COASTAL HAZARD STRATEGY

COASTAL EROSION MANAGEMENT MANUAL

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FORWORD

The coastal environment. It is one of the most treasured parts of our region, but one which we also sometimes take for granted. Despite its great value, it is also an environment we know little about. The coastline of Auckland is a regionally and nationally significant resource comprised of over 2100km of coastline with many inlets, bays, beaches and harbours, not to mention the splendid Hauraki Gulf. Some of this is highly developed, some is natural, but much of it is under pressure from use and development of many types. In some places buildings, dwellings and assets have been located in hazardous locations. In others, coastal structures and works have been designed, located and built with insufficient recognition of coastal processes, or a proper decision making process for achieving protection of assets and the coast.

The Resource Management Act has established a management system for the coast based on the development of a regional policy statement and a regional coastal plan. The Auckland Regional Policy Statement is now operative and includes a chapter on the coastal environment, as well as one devoted to natural (including coastal) hazards. The proposed Regional Plan: Coastal is also well advanced. The pRP:C gives a great deal of detail on what outcomes are to be achieved on the coast, and the way in which activities and their effects are to be managed. It also contains detailed policy on the management of coastal hazards.

The purpose of the Coastal Hazard Strategy and the Coastal Erosion Management Manual is to provide further detail on the way in which the ARC, in conjunction with the Territorial Local Authorities of the region, the public, tangata whenua, consultants, planners, engineers and all those with an interest in the coast can achieve the outcomes sought by the RMA, ARPS and pRP:C. They provide detail on how to avoid coastal hazards (the Coastal Hazard Strategy), and how to mitigate coastal hazards where they exist (the Coastal Erosion Management Manual).

I commend this Strategy and Manual to you and seek your assistance in their timely implementation.

Patricia Thorp

Chairperson

Environmental Management Committee

Auckland Regional Council

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Have we left out any measures/practices commonly used or which you find useful? If so, please list them below and if possible any design guidelines for us to include:

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The Coastal Environment Team, Auckland Regional Council, Private Bag 92012, Auckland.

COASTAL HAZARD STRATEGY

PART I

1. INTRODUCTION – COASTAL HAZARDS IN THE AUCKLAND REGION

Coastal processes are a critical part of the natural character of the dynamic coastal environment. As with any system, the coastal environment oscillates through a range of conditions, and occasionally experiences extremes. These fluctuations and extremes help develop the characteristics of the system, and are a natural part of them. Natural hazards arise from the interaction of such processes with human use, property, or infrastructure. Left to its own devices, there is nothing inherently "hazardous" about the coast. The risk imposed by hazards is the result of this nature/human interaction, and the effect of these dynamic and variable processes on the rather less dynamic and more static human resources of the coast.

The Auckland Region is the most developed urban area in New Zealand. It has a population of almost 1.1million people (about 29% of the total population of New Zealand). It has over 1500km of coastline, and development has tended to concentrate towards the coast. Much of the urban part of the region is sited on a narrow isthmus between two large harbours. Residential developments have been undertaken immediately landward of eroding soft sedimentary cliffs, and also on the accreted lowlands behind beach systems. As a result, there are significant parts of the Auckland urban coastline which are exposed to some types and degrees of coastal hazard. Any strategy for coastal hazard management in such areas needs to be sensitive to the existing development, and also the costs and benefits of protecting that development from natural coastal processes.

2. EFFECTS OF COASTAL HAZARDS

Natural coastal hazards can adversely affect the economy and the health, wellbeing and safety of people and communities. They may also adversely affect vegetation and habitat; public access to and along the coastal marine area; visual character; amenity values; recreation; and aspects of coastal heritage, such as historic buildings or structures (which might include some older shore protection structures). Sites and areas of significance to Tangata Whenua, such as waahi tapu, urupa, middens, and other taonga, may also be at risk from natural coastal hazards.

Loss or modification of the natural character of the coastal environment is a major issue facing coastal management in New Zealand. The preservation of the natural character of the coastal environment, and its protection from inappropriate subdivision, use and development is a matter of national importance in the Resource Management. Many of the key elements of the character of the coastal environment are found in its immediate landward components. These are the same areas and features which typically become considered hazardous when encroached upon by human use and development.

Landforms such as beaches, dunes, cliffs, estuaries are typically within those areas termed hazardous. Flora and fauna including coastal vegetation, nesting feeding and roosting birds also tend to be most concentrated in the narrow area of land immediately next to MHWS. Many of these features are in a state of dynamic equilibrium, ensuring that the coast and its physical features are able to absorb and recover from the effects of natural coastal events such as storms, tsunami and sea level rise. For example, a well vegetated foredune is able to absorb the effects of occasional storms, and protect adjacent coastal settlements without the need for foreshore structures.

Therefore, the avoidance of coastal hazards is reliant upon, and is facilitated by the preservation of these natural coastal features and their protection from encroachment by human use and development.

3. A COASTAL HAZARD STRATEGY

This document presents the Coastal Hazards Strategy for the Auckland region. It contains the theoretical basis, philosophy and methodology towards hazard management. The Strategy will guide the ARC as it meets its statutory functions and obligations, and will also form a component of the wider ARC approach towards all natural hazards. It is expected that the strategy will act as a guideline for City and District Councils when managing coastal hazard management issues, and will also be of use to developers, planners and property owners.

This strategy contributes towards the overall hazard management framework established by the ARC. That framework integrates analysis, planning, response and recovery aspects of hazard management. It also serves to identify the existence of coastal hazards in the Auckland region. The overall framework encompasses the following phases:

Mitigation: includes hazard and risk analysis, public awareness and education, and risk reduction measures.

Preparedness: includes the planning, training and providing equipment and resources for response agencies.

Response: includes all activities and measures taken to protect a community from an actual or forecast event.

Recovery: includes the work required to restore a community to their pre-event capability.

This strategy is the first comprehensive and integrated approach to the avoidance and mitigation of coastal hazards. It also provides mechanisms to promote the other three steps identified above. More specific civil defence strategies relating to response and recovery will also be developed and published for specific types of coastal hazards.

Implementing the above actions could be achieved in a number of ways. Any strategy must acknowledge the extent of development which has already occurred in the Auckland region, the particular geographic characteristics of development, and the types of coasts which characterise the region. It must also accept that this development has created coastal hazards.

4. OPTIONS FOR MANAGING COASTAL HAZARDS

At a general level there is a wide range of options available for managing hazards, which are described by the above continuum. Over time, typologies of approaches for managing natural coastal hazards have evolved in international literature. A useful typology is set out in Figure 1. The options are not mutually exclusive, and it is usually necessary to link selected elements of each into a unified approach (Kay et. al., 1994). From Figure 1, it can be seen that the total programme of coastal hazard management for the Auckland region covers a number of programmes including this strategy (an example of damage prevention), the Coastal Erosion Management Manual (an example of event protection- refer Appendix 1). Other options such as insurance programmes (an example of a loss distribution approach), which are outside the control of the Auckland Regional Council, will also have an influence. Risk acceptance is also commonly applied in situations where the risk is low, or the consequences associated with the hazard are also limited. It is highly unlikely that any one of the above options will adequately deal with coastal hazards in a given area (Kay et. al., 1994). A "unified program" which integrates a range of measures is much more likely to succeed.

> *"The aim of hazard planning is <u>to integrate a range of measures</u> from different approaches into a unified programme for <u>reducing the hazard</u>, and thereby loss-potential, along the entire length of coast within the jurisdiction of an agency(ies)"* (Kay et. al., 1994).

A core component of any approach is the identification and quantification of the hazard that is present. Commonly used methods of managing coastal hazards (in terms of damage prevention) range from land use rules, which are varied depending on the proximity of the land to the coast and the type of development, to development criteria that are considered when a proposal is considered. Coastal hazards can also be assessed by individual property owners or land developers when initially developing or redeveloping a site, and can assist in determining the most appropriate location for buildings and other structures. The pending development of Omaha south is a useful example of this process. While such an approach can lead to positive results in terms of site specific hazard avoidance, it is more appropriate to identify hazardous areas for complete coastal units (entire beaches from headland to headland, or cliff sections) to ensure a consistent and equitable approach.

Event protection mechanisms have historically been the most often used method of hazard management. They are reactive in nature, requiring an immediate response to an existing hazardous situation which has developed (such as residential development in the active coastal zone). Because of immediate threat to financial and infrastructural, the most common response to event driven coastal hazards is hard engineering structures such as seawalls.

Figure 1
A Typology of Options and Measures for Managing Natural Hazards (adapted from Kay et. Al., 1994)

MANAGEMENT OPTIONS

Event Protection
"Hard" approaches (e.g seawalls, groynes)
"Soft" approaches (e.g beach nourishment, dune protection)
Coastal Erosion Management Manual

Damage Prevention
Avoidance (e.g prevent development)
Modify loss potential (e.g relocatable buildings)
Coastal Hazards Strategy

Loss Distribution
Individual measures (e.g insurance)
Community measures (e.g insurance)

Risk Acceptance
Various thresholds (do nothing)

Unified Approach
A mix of selected measures from above options.

The first stage of the strategy consists of two major actions (refer Part IV) designed to overcome several impediments to better management of coastal hazards. These as:

- Dispersed and incomplete data and information. It has been historically difficult for the ARC, TA's, consultants and landowners to find information about hazardous coastal areas;

- There is considerable uncertainty about the range of approaches or methods for determining coastal hazards, and there are no universally accepted ways to determine which ways are more or less appropriate. There is also less than complete information on the methods used by various experts, the ways and locations in which they have been tested, the results achieved, and their applicability to sites in the Auckland region.

The strategy does not present results in terms of identifying coastal hazards for specific coastal areas in the Auckland region. This task will require a long-term commitment from the ARC, and also from the TLA's and those individuals and groups who own and/or develop land in the coastal environment. The strategy does provide guidance on those parts of the coastline of the Auckland region where the ARC considers priority should be given to coastal hazard investigations. It also provides a means of accessing all known existing data on coastal hazards through the region. Finally, the strategy sets out a series of approaches and techniques to assess and evaluate the extent of hazardous areas in the coastal environment. It is expected that these approaches will act as a consistent set of standards by which all those involved in coastal hazard management in the region can sustainably manage coastal hazards.

PART II

5. PURPOSE OF THE STRATEGY

The purpose of this document is to guide the ARC, and also TLA's in the sustainable management of coastal hazards in the Auckland region. In doing so, it must not be inconsistent with the provisions of the Act and the NZCPS, but more specifically, must reflect and assist in the implementation of the issues, objectives, policies and methods of the ARPS and the pRP:C. It should also allow for a sensible assignment of responsibility between the ARC, TA's and others to ensure that coastal hazards are sustainably managed.

The specific purposes of the strategy are:

- To meet the requirements of the Resource Management Act especially in relation to Sections 5, 6 and 7, Section 30(1)(c)(iv) and Section 31(b);
- To implement the policy requirements of the NZCPS;
- To meet the requirements of the ARPS and the pRP:C;
- To work with, and assist Auckland's TLA's in meeting their individual and joint responsibilities under the RM Act, and also other relevant legislation.

6. GOALS OF THE STRATEGY

In order to achieve the purpose of the Strategy, a series of goals need to be set, and then met. The goals of the strategy, which are in addition to, and do not substitute for those already set in the ARPS and the pRP:C. are:

⇒ To avoid, remedy or mitigate the adverse effects of natural hazards on subdivision, use and development of the coastal environment;

⇒ To substantially raise the awareness of those responsible for coastal hazard management, and also the public to the risk posed by natural coastal hazards, and to progressively identify the vulnerability of people and communities to them;

⇒ To foster and raise community resilience to natural coastal hazards, and reduce resistance

⇒ To significantly reduce the risk of loss of property, amenity value, economic costs and the actual and potential adverse effects on natural and cultural resources that result when coastal hazards are created.

As a result of these objectives and goals, it is possible to describe an overall approach towards coastal hazard management in the Auckland region. Any assessment of coastal hazards should be based on a knowledge of the fundamental physical coastal processes which govern the response of the coast to various forcing factors, a thorough assessment of human uses and physical aspects of coastal systems, their interaction, and sustainable management practises in order to recognise coastal hazards and provide options to remedy, mitigate or avoid them. A multidisciplinary and holistic approach is therefore most likely to succeed (Kirk, 1999).

The adoption of a holistic approach embraces a philosophy of coastal management which is intricately linked to the underlying principles of the Resource Management Act. Such an approach is flexible, and is able to accommodate a range of environments and circumstances. Kirk (1999) has set out a series of generic steps that should be undertaken in any coastal hazard assessment. The precise techniques used with each step will vary depending on the coastal landform type under investigation. This strategy sets out both the generic approach, and provides information on specific techniques and approaches to be used as part of that overall approach. The approach reflects a process conceptualised by Professor R Kirk and Dr M Single. It builds on the premise that interpreting coastal processes and, human uses, existing legislation and planning regimes cannot be undertaken by untrained personnel and requires an integrated approach towards coastal hazard management. The overall approach is illustrated in Figure 2. From this it can be appreciated that other programmes being undertaken by the ARC contribute towards this process. For example the Wave Climate Strategy and the Coastline Monitoring Programme both contribute data towards the identification of parameters for coastal sites, in terms of physical processes. Furthermore, the Coastal Erosion Management Manual is integral in determining management strategies to avoid, remedy or mitigate coastal hazards.

Kirk and Single recommended that specific to each area of coast under consideration, an individual or group should be identified that has the appropriate training and expertise in the following areas:

- Coastal geomorphology and processes, in order to assess physical aspects of the coast, processes and the physical dimension of the hazard issue;

- Human use and activities in the coastal zone (industrial, residential, recreational, cultural), historical patterns and reasons for settlement;

- Planning and zoning (if relevant) of the coast. It is important to understand existing land uses and proposed uses of the coastal site;

- Legal issues that affect the coastal site with respect to land ownership;
- Cultural issues and values at the coastal site;
- Ecological assessment of the coastal zone in order to determine any special values that may impact on management strategies.

Kirk (1999) emphasised that the selection of personnel to undertake such an assessment needs to reflect the importance of engaging people with relevant training and skills who are able to assess coastal characteristics. This is especially important in relation to physical processes, where information tends to be deficient. Decisions may be based on informed expert judgement of how the coast behaves.

As shown in Figure 2, there are two principal sets of information that need to be gathered when identifying coastal hazards. Options chosen to avoid, remedy or mitigate the identified hazards also need to take account of existing characteristics and uses of the coast.

The process for identification of the parameters of the coastal site involves an assessment of the various physical and human parameters set out Figure 2. These are described in full detail in Kirk (1999, pp 7-17).

The next step involves identification of the physical dimensions of the hazard. By combining information on natural processes and human activities at the coast it is possible to identify the type of hazards prevalent at a site and the areas subject to these hazards. Typically, overlay maps depicting human occupation and activity boundaries combined with wave runup, storm surge, inundation levels and erosion deposition sites can clearly convey which areas of the coast are subject to hazards and which areas are not.

The typical outputs of hazard identification were summarised by Kirk (1999) as being:

- ◊ Summary maps depicting: boundaries of human development or use, areas of the coast subject to erosion, inundation or dynamic change.
- ◊ Determination of major hazards at a coastal site (e.g erosion, flooding and inundation, sedimentation).
- ◊ Identification of hazardous areas

Figure 2

Overview of Steps in Coastal Hazard Assessment

(Kirk; 1999)

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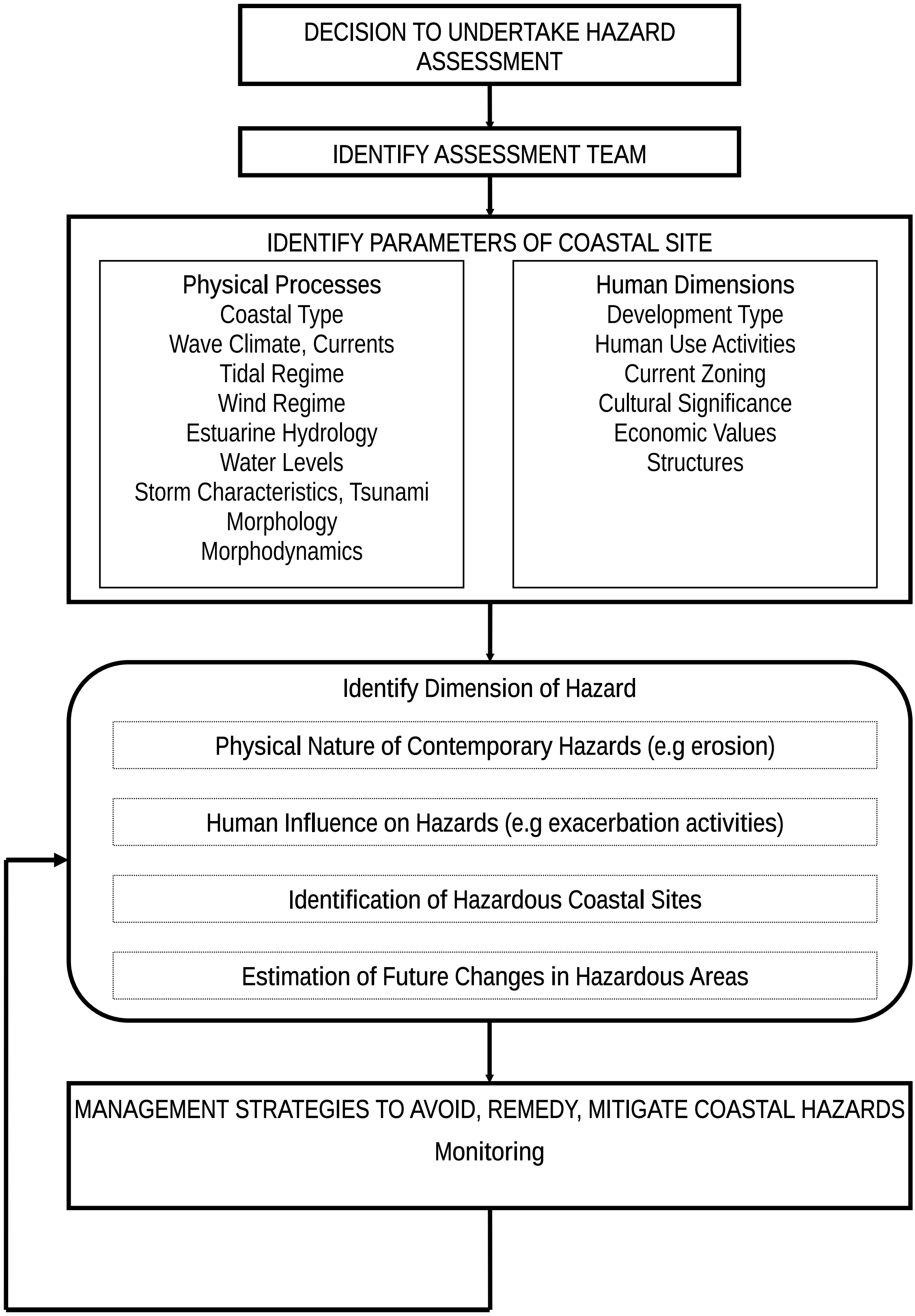


PART III

7. STATUTORY FRAMEWORK

The management of natural hazards is undertaken via the provisions of the Resource Management Act 1991 (the Act). As such, the avoidance or mitigation of coastal hazards must be undertaken in a manner which achieves the purpose and principles of the Act and with the objectives, policies and rules of the statutory policy statements and plans which derive from it. These include the New Zealand Coastal Policy Statement (NZCPS), the Regional Policy Statement (RPS), the proposed Regional Plan: Coastal (RP:C), and proposed and operative district plans. Other relevant statutes include the Building Act 1991, the Civil Defence Act 1983, and the Local Government Act 1974.

Sections 30(1)(d)(v) and 31(b) of the RMA impose on regional councils and Territorial Local Authorities(TLA's) respectively the function of controlling any actual or potential effects of the use, development, or protection of land, including the avoidance or mitigation of natural hazards. This strategy arises from commitments made in the proposed RPS and the RP:C, and also aims to implement the relevant provisions of the RMA and the requirements of NZCPS.

The relevant provisions of these Acts, policy statements and plans are set out in Appendix 1.

8. RESPECTIVE ROLES AND RESPONSIBILITIES OF TLA'S AND THE ARC

TLA's and Regional Councils both have responsibilities for natural hazards management under the RMA (1991), the Building Act (1992), the Civil Defence Act (1983), the Local Government Official Information and Meeting Act (1986) and a range of other legislation. A joint planning approach will be required to ensure that overlaps or gaps in policy relating to natural hazards do not occur.

S. 62(h)(a) of RMA (1991) requires that the Regional Policy Statement clearly establish the respective roles and responsibilities of the regional council and TLA's with respect to hazards. If this is not stated then by default the responsibility falls to the regional council.

Currently there is no clear assignment of responsibility for the various hazards in the Auckland Regional Policy Statement. The ARC is working towards a variation to the

RPS, to clarify this situation.

PART IV

ACTIONS

In order to implement the objectives and goals of the strategy, a series of actions have been identified. These are aimed at ensuring that users of the strategy, including the public, local authorities, scientists, engineers, planners and consultants have a sound base of information and techniques upon which to assess and manage coastal hazards. In this way, a consistent and rigorous approach to coastal hazard management will be taken throughout the region. The actions are:

- the development of a coastal hazards directory
- the presentation of representative hazard identification methodologies
- the development of an implementation strategy.

The first action describes a directory which the ARC has established to assist in the collection of base data on the coast. The directory was created to overcome problems associated with a dispersed and largely inaccessible data set on coastal processes, geology and management. The ARC has developed a bibliographic directory which allows users to search geographic areas of interest for any publications, research documents or other pieces of information relating to that area. This directory- the “Coastal Hazards Directory” is a windows based product which allows users quick access to information and references.

The second action is the identification of a series of technical and professional methods to assist in the determination of coastal hazards in a particular area. This work was undertaken due to difficulties, both regionally and nationally, with identifying a representative set of approaches towards coastal hazard identification and management. Previous attempts had tended to focus on only one technique, rather than assessing a range of approaches.

Four separate approaches have been evaluated in this strategy. They range from quantitative and empirical methods, through to semi-empirical approaches which integrate physical and human factors. Although there are many more approaches than this potentially available, these four have been chosen as being reasonably representative of a range of methods from empirical to qualitative, and mixtures of both. The ARC does not have a preference amongst these four, and all are considered appropriate methods to ensure that the objectives of this strategy (and more broadly the RMA, NZCPS etc) are met.

The overall aim of this section is to provide information and approaches towards coastal hazard management which will be of use to those involved in coastal hazards. It is anticipated that both the Coastal Hazards Directory, and the summary of techniques will act as a resource for coastal hazard practitioners to ensure a consistent and high quality approach towards this issue is taken.

9. ACTION 1: COASTAL HAZARDS DIRECTORY

The directory allows coastal hazard information to be entered, viewed and questioned in a computer based 'Windows' environment. Hazard information is presented as bibliographic references with a brief abstract of what the document contains. At present the directory contains 1437 entries.

Each entry describes the location for which the information is relevant, the type of information, where it is stored and its quality. The exact location to which the data is relevant is provided using NZMS 260 Series grid co-ordinates. The directory operates using a nested geographic reference system. The coast of the region has been divided into 12 broad areas. These are:

- Firth of Thames
- Hauraki Gulf Islands
- Kaipara Harbour
- Kawau Island- Long Bay
- Mangawhai- Tauwharanui
- Manukau Harbour
- Papakanui-Whatipu
- Port Waikato-Awhitu
- Tamaki River- Kawakawa Bay
- Torbay-North Head
- Waitemata Harbour
- Auckland General

Each of these general areas is then subdivided into smaller specific areas. Each specific area is based on geomorphic features (such as a beach, or a section of coastal cliff) with the typical resolution being about 1-2km. Users are able to search either a general area (including the entire region) or are able to identify the specific section of coast they are concerned with and gain detailed information for that area.

The information on the directory has assisted in the determination of pilot sites where appropriate hazard identification techniques can be applied. Site have been chosen where a reasonable amount of information already exists, which will assist in the hazard identification and management process. The directory also highlights information needs and provides links to other coastal science programs including the coastline monitoring program, the wave strategy, the Coastal Erosion Management Manual and the CoastCare program. The information on the directory will also be useful for coastal permit, subdivision consent and building consent applications.

9.1 QUERYING THE DIRECTORY

The information on the directory has been classified by various different parameters. These include location as detailed above (general and specific), subject of the data (a range of 12 subjects based on coastal geomorphology and hydraulics are listed), the title, author and year of publication (if known), and the type of data(21 data types are listed including journals, CD Roms, University theses, newspaper clippings). Information can be found by using any single parameter, or a collection of these. For example

Subject = Waves;

General Location = Mangawhai- Tawharanui;

Specific Location = Pakiri Beach

Corporate Author = Auckland Regional Council;

The query is answered with a list of references that meet the requested requirements e.g. a query on waves at Pakiri would yield a query result screen (Figure 3) and a matching report (Figure 4) featuring the selected information. In this example the directory come up with 8 entries which can be scrolled through on screen, and printed if necessary.

Figure 3
Query Screen for The Coastal Hazards Directory

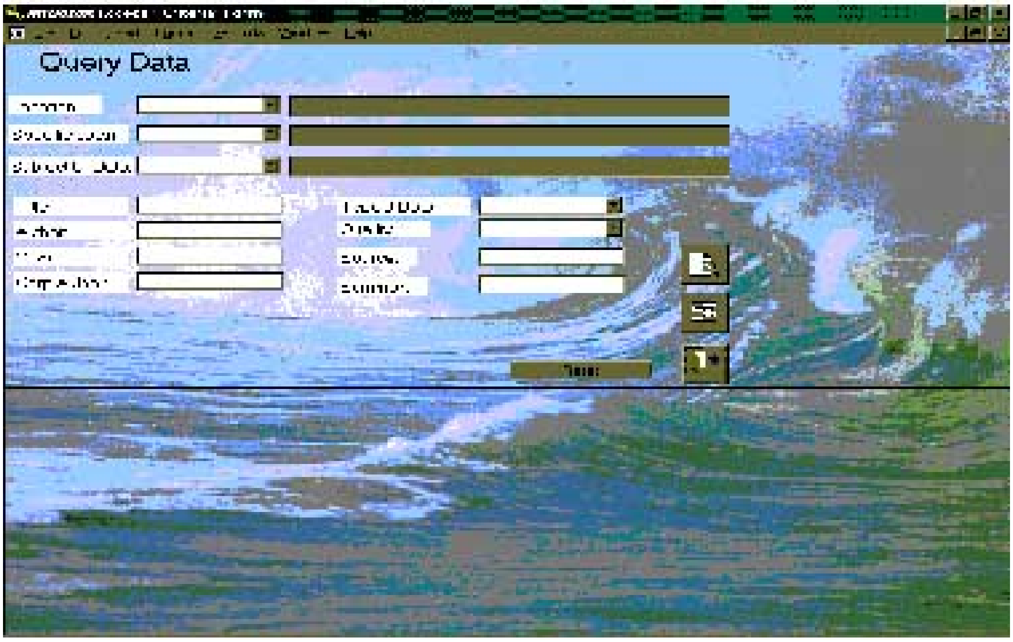
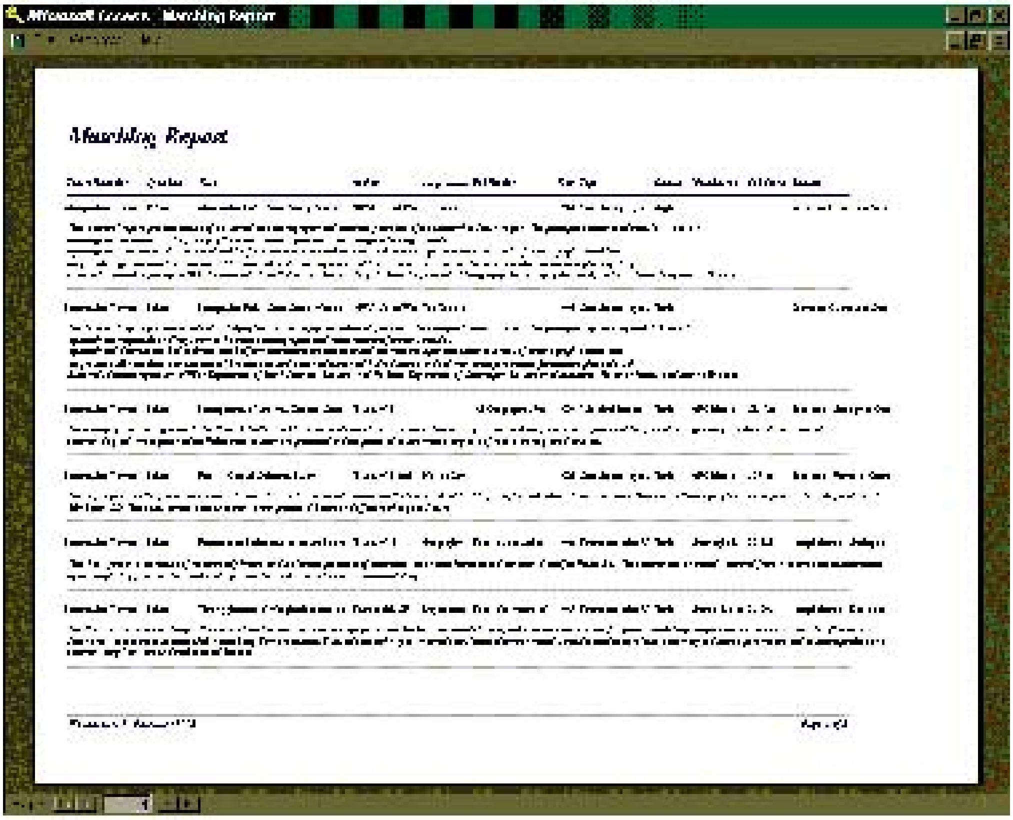


Figure 4
Matching Report Screen, Coastal Hazards Directory



9.2 FUTURE DEVELOPMENTS OF THE COASTAL HAZARDS DIRECTORY

The directory is now in the process of being added to the ARC internet web site. At the web site, users will be able to search for and view information as described above. The site will also contain e-mail and address contacts for the coastal hazards directory administrator at ARC where new additions of coastal hazard research can be sent and then added to the directory.

To ensure the future success of the directory, all parties potentially interested in the coastal hazards will be encouraged to use it. Any new pieces of coastal hazard information will be added to the directory as soon as possible to ensure the completeness of the record.

10. ACTION 2: DETERMINING THE APPROPRIATE HAZARD IDENTIFICATION TECHNIQUES

Specific action in relation to an actual or perceived coastal hazard requires an evaluation of the spatial extent and magnitude of that hazard (refer earlier discussion). There are a wide range of quantitative and semi-quantitative techniques available which have been applied by various technical experts to various locations. At present there is no standard method or suite of methods which are universally considered more acceptable or rigorous than others. This is not unusual given the wide range of coastal environments and circumstances in New Zealand. Most of the most commonly applied techniques in New Zealand have however been tested by peer review and scrutiny at the Environment Court (Planning Tribunal pre 1997).

The purpose of this section of the strategy is to set out a range of techniques and approaches which are considered to be appropriate to the types of coastal environments in Auckland, and which have also been sufficiently well tested to be confident of their technical rigour. However the intent is not to tightly prescribe those as the only techniques available or acceptable to the ARC, as the specific circumstances of a particular location may demand another and/or a more innovative approach. Also, it may be that a site involves a combination of several of these approaches in order to reach a reasonable and justifiable management solution. In any case, the application of technical methods to identify the extent of hazardous areas should only be undertaken as part of a total coastal hazards assessment as set out in Figure 1.

The ARC will, in accordance with the provisions of the pRP:C, advocate the use of these techniques by all those involved in coastal hazard management. To promote this, the ARC will apply these techniques to a series of trial sites around the Auckland region. This process will be described in more detail in Part V of this Strategy.

10.1 UNCERTAINTY IN COASTAL HAZARD DETERMINATION

Coastal science is a relatively young discipline (evolving essentially since WWII), and consequently, one in which knowledge is constantly evolving. Several of the approaches detailed in the strategy involve parameters which are still open to considerable scientific debate in the literature. Any use of these parameters, and the formulae that they form part of, must therefore recognise this inherent uncertainty. A discussion on three such parameters is set out below. These are global warming & sea level rise, the notion of a “closure” depth, and time frames or “Planning Periods” in hazard assessments. The purpose of this discussion is **not** to endeavour to discredit those techniques which use these factors, as each technique presented here is considered to be fully valid for use in the appropriate circumstances. It is merely to acquaint the reader with the technical limitations which exist generally in coastal science and management, and ensure that the reader is alert to their existence when applying results to real situations.

10.1.1 SEA LEVEL CHANGES INCLUDING ACCELERATED SEA-LEVEL RISE

There is substantial evidence of historical sea level rise on a world scale, and also from long term tide gauge records at Auckland, Wellington, Lyttelton and Dunedin (Schofield; 1960, Hannah; 1990, Gibb; 1991, Healy; 1993).The tide gauge information relating to Auckland has been reported earlier in this strategy and is not repeated here. These general trends however need to be applied with great care to specific situations, and according to Kirk (1999) the figures derived by Hannah (1990) are the most appropriate figures to use for the Auckland region.

Other data from New Zealand also assists in understanding the variability of sea-level. Bell and Goring (1997) analysed tide gauge data from Moturiki Island in the Bay of Plenty. They founds that a downward trend in the Southern Oscillation Index from 1973-1994 (and a resulting increased frequency of El-Nino weather patterns) had contributed to a downward trend on both sea surface temperature, and to a lesser extent Mean Sea Level. However, Bell and Goring note that such a change was detected in the tail end of the dataset used by Hannah (1990), and masks “the underlying long-term secular rise in sea level.”(Bell and Goring, 1997, p1034). More recently, a similar analysis has revealed the same general pattern with the Auckland tide gauge (Figure 5).

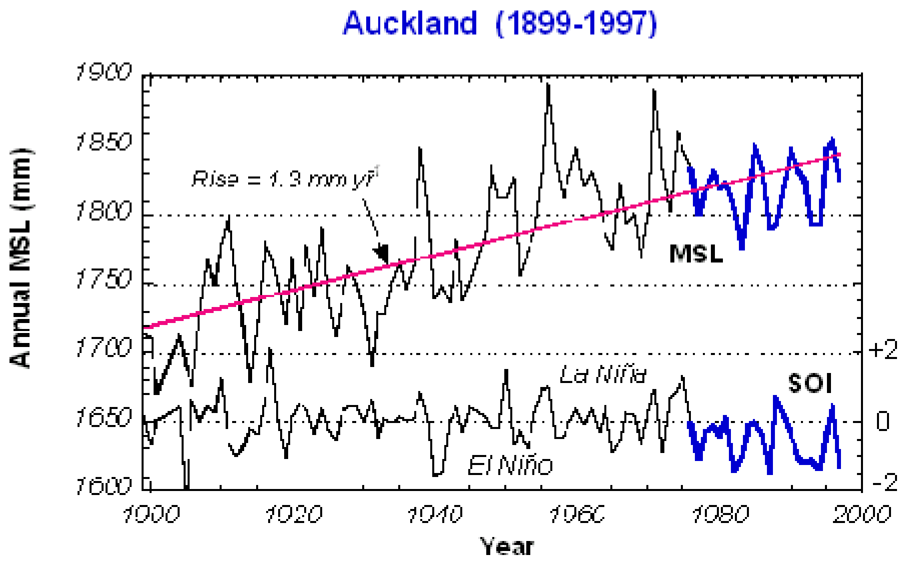


Figure 5. Annual Mean Sea Level (MSL) for Port of Auckland and Southern Oscillation Index (SOI) showing a linear trend in sea-level rise this century. The blue lines emphasise the period since 1977 of unusually persistent El- Nino events (NIWA).

There has been considerable debate regarding the possibility of an acceleration in the rate of sea level rise due to anthropogenic effects on the atmosphere and the entire biosphere. These have been referred to as the enhanced greenhouse hypothesis, or more commonly the "greenhouse effect" whereby increased atmospheric CO_2 and chloroflourocarbon concentrations induce a substantial atmospheric warming (in effect an amplification of the natural radiation balance of the atmosphere) followed by presumed polar ice melting, thermal ocean expansion and consequent sea level rise at a rate greater than "background". Early predictions of sea-level rise by the US Environmental Protection Agency (Hoffman et. al. 1983, Barth and Titus 1984; Titus 1986 a,b *reported in* Healy and Dean in press) and the National Research Council (Thomas, 1986 *reported in* Healy and Dean in press) were for increases of between 0.6 and 2.3m by the year 2100, with a most likely value of about 1m.

Since that time these predictions have been continuously reviewed and updated. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organisation (WMO) and the United National Environment Programme (UNEP) to assess the available scientific, technical, and socio-economic information in the field of climate change (IPCC, 1996). In 1990, the IPCC released its first assessment of that information in terms of the likely effects on *inter alia* global mean sea level. The report is the compilation of work by 170 scientists from 25 countries, and was peer reviewed by another 200 scientists. As a result the work reflected a high degree of international consensus on the topic (Gibb, 1991). Under its Business as Usual (BAU) scenario, global mean surface air temperature was expected to rise by 1° C by 2025, and by 3° C before 2100, with an uncertainty range of 0.2-0.5° C per decade. The resulting range of **global** sea level rises suggested that a rise in the rate of sea level increase from the present 2mm/yr to about 7mm/yr by 2100 was the “best estimate” (Gibb, 1991).

Since this time, the IPCC estimates have been updated. The IPCC released its second assessment report in 1995, and continues to produce technical papers and develop methodologies for use by parties to the climate change convention. A third assessment report will be completed around the year 2000. The 1995 report presents detailed information on changes in atmospheric concentrations of greenhouse gases and particulates, and distinguishes between those which have a positive radiative effect (such as CO_2) and those which have a negative (cooling) radiative effect (such as anthropogenic aerosols).

The report presents some definitive conclusions in terms of the effect of human activity on the global climate. The report states that while year-to-year variations in weather can be large, analysis of meteorological and other data over large areas and over periods of decades or more have provided evidence of systematic changes. Included in these are:

- global mean surface temperature has increased by between 0.3 and 0.6° C since the late 19th century;
- recent years have been the amongst the warmest since 1860;
- global sea level has risen by between 10 and 25cm over the past 100 years and much of the rise may be related to the increase in global mean temperature

Further, the report states that the “balance of evidence suggests a discernible human effect on global climate”. For the mid-range IPCC emission scenario, the models used by the IPCC project an increase in global mean surface air temperature relative to 1990 of about 2° C by 2100 (1/3rd lower than the 1990 estimate). This is due to lower emission scenarios (especially CO_2 and CFC’s), the cooling effect of sulphate aerosols, and a better understanding of the carbon cycle. The lowest IPCC scenario would see a rise in temperature of only about 1° C by 2100. In any case, the report notes that any rate would be higher than any experienced in the past 10,000 years, but the actual annual to decadal changes would include considerable natural variability.

“Average” sea-level is expected to rise as a result of thermal expansion of the oceans and the melting of glaciers and ice-sheets. The IPCC best estimate for this is for an increase in sea level of 50cm from the present until 2100, and is 25% lower than the 1990 estimate. A high estimate would see sea level rise by 95cm by 2100. Sea level would continue to rise at a similar rate beyond 2100, even if concentrations were stabilised. There appears to be no discussion in this report of the hypothesis (refer to discussion in Gibb, 1991) that global warming could increase polar precipitation to the extent that it could offset ice-melt.

The report notes that confidence is higher in the hemispheric to continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. There is also more confidence in temperature projections than in hydrological changes.

According to Kirk (1999), all such projections are only of tenuous relevance to sea level rise in the Auckland region. The preferred position of Kirk (and subauthors Kench and Single) is to assume, in the absence of absolute evidence to the contrary, that sea level rise will not accelerate, but will continue to exhibit a linear trend over time. Hannah's best estimate on this basis (which add ice-melt and thermal expansion to existing sea level rise) was for a 0.2-0.4m increase in MSL by 2050. Kirk noted that these estimates were accepted by the New Zealand Climate Change Committee and, therefore, could be used as a basis to predict changes in hazard areas in Auckland.

The policies of the Auckland Regional Policy Statement and the proposed Regional Plan: Coastal (refer to Appendix 1) advocate use of the best available estimates of sea level rise for the area in question. The IPCC estimates provide a broad overview when determining what local sea level responses might be. These, together with site specific measurements (such as those reported from Hannah (1990)) are considered to be the most reasonable and appropriate information upon which to base any evaluation of climate change and resultant sea-level rise. Even so, it must be accepted that local conditions (geological and meteorological) may modify these predictions, either positively or negatively. This information becomes important in that several of the techniques set out in this strategy require as input data an assessment of projected sea-level and resulting erosion.

It was noted by Kirk (1999) that an increase in sea-level in itself is unlikely to promote hazards except in very low gradient coastal settings in which development is situated in close proximity to present MSL. According to this view, it is extreme events operating above this increase in base level that could extend hazardous areas in developed coastal sites.

10.1.2 "Closure Depth"

The term "closure depth" is related to a water depth at which repeated surveys of the sea floor show no change in elevation over time. At locations closer to the shore, sediment movements caused by wave driven currents cause elevation changes. The most common application of the concept is in formulae to ascertain the effect of a rise in sea level in terms of coastal erosion. The formulae of Bruun is the most frequently cited method of ascertaining erosion caused by sea-level rise, although more recent techniques by Hellermeier treat the issue in a statistical sense and attempt to define inner and outer limits for swell and storm conditions.

Research by Hilton (1990) and recent work undertaken by NIWA in the Pakiri embayment has tended to confirm the existence of a sedimentological and morphological change in conditions at about the depth which correlates to a calculated storm condition closure depth of -15 metres. This information has been assessed as confirming the hypothesis that some east coast beach systems are closed (at least at a 10^0- 10^1 year time frame) to significant inputs of sediment into the nearhsore system landward of that closure depth.

However not all coastal researchers agree on the validity of the concept. According to Kirk (1994), the concept of a closure depth has not been the subject of very much conclusive research in international scientific literature. Further, Kirk suggests that it is questionable to make the determination of a finite hazard zone width on land, conditional on the identification of a very poorly known depth somewhere on the seabed off the coast. Kirk concludes that the extent of land subject to a hazard is only weakly sensitive to a closure depth, if one exists. Kirk (1999) amplified these reservations. He referred to experiments in the laboratory by Dean (1990) who compared results of the (Bruun) model with field sites where sea level had historically been rising, and found that the model was a poor predictor of shoreline erosion (Kirk, 1999). The basis for the poor prediction was reported as being the 2 dimensional nature of the model which does not account for cross-shore sediment fluxes and changes in sediment budget. Dean considered that these could account for up to 50% of shoreline retreat, and would mask shoreline erosion associated with sea level rise.

Most recently, Pilkey, Theiler, Young and Bush (1999) in commenting on the use of the closure depth notion in the GENISIS shoreline evolution model stated that *"we find no oceanographic basis for the existence of a closure depth. Rather the geological literature is full of data suggesting significant sediment transport from shallow into deep water and vise versa…Current-meter studies…indicate such a dividing line between the shoreface and the inner shelf does not exist."*

On the basis of the widely divergent views, it is concluded that there is no scientific consensus one way or the other on whether the idea of a closure depth is a physical reality. It is also possible that specific oceanographic and geomorphological conditions allow for its existence in some locations and not in others.

The exact effect of this on hazard assessments is also unclear. However, it places an onus on practitioners to at least undertake a sensitivity analysis of any results by both varying the assumed/measured closure depth, and also more generally by applying coastal hazard assessments with and without the entire sea-level rise factor. This can be achieved by not considering the factor at all, or by assuming that the values for other hazard parameters are the same regardless of sea-level rise, and extending their influence based on a vertical rise in still water levels (Kirk, 1999) (i.e avoiding using any sort of formulae). Extreme or significant variation in resulting hazard zone determinations might suggest that the technique is over-sensitive to factors whose credibility are presently under question.

10.1.3 PLANNING PERIODS

Several of the techniques set out rely on the use of a time dimension in their assessments. These are used to convert annual rates of change in shoreline position to a time frame of more significance to land use planning such as 50 or 100 years (the two most commonly used). As with the sea-level rise issue, this matter raises potential difficulties in terms of the validity of the assumptions that need to be made. In effect, the methods by necessity assumes that processes and trends observed in the contemporary and geological record can be transposed forward 50 or 100 years. This assumes a linear progression in the trend over that time frame.

Both Kirk (1994) and Kirk (1999) expressed reservations with this approach. Kirk noted that in his view there were no scientific fields in which credible 50 or 100 year forecasts could be made, and that, in his view *"the calculation of a zone by multiplying a hypothetical rate of retreat by a number of notional years…is neither necessary or desirable."* Kirk also considered that the method will misrepresent actual shoreline behaviour except at sites on sandy beaches where the coast is undergoing persistent retreat. He considered that the method could not apply to shorelines that oscillate about average positions, to spit tips that fluctuate widely in form and position at erratic time intervals, or to gravel beaches.

Kirk (1999) expanded on these issues. He considered it was seldom possible to confidently predict the precise location of the coastline for any specified time. The approach advocated by Kirk is to accept that the coast will continue to fluctuate within a similar envelope of change to that which it has fluctuated in the past. In this scheme, it is the identification of the envelope of change (especially its extreme boundaries) which becomes the important variable to define. Kirk expands upon this matter by questioning the (implicit) assumption that a coastal hazard line based on mutliplication of an annual rate of erosion by 100 years will protect development for 100 years, or against a low probability high impact event such as 1% AEP ("1 in 100 year") storm. Kirk (1999, 39) states that *"such statements confuse a probability and a risk with a time period…*(for example)…*few would argue that constructing a stop bank of a river to a level that will contain the 1% risk flood protects the adjacent land from flooding for 100 years."*

Kirk considers that the technological capacity and understanding of coastal systems does not exist to be able to accurately predict coastal changes at significant time periods into the future (Cowell and Thom, 1994, in Kirk, 1999). This is based on the fact that scientific understanding of coastal responses in still at a rudimentary stage.

For example, erosion of a coastline is rarely linear. Instead erosion episodes occur for many coastal sites at inter-annual or decadal periods and exhibit spatial variability and magnitude differences. Kirk therefore concludes that *"it stretches scientific credibility to use a linear erosion rate interpreted between two time periods."* (Kirk, 1999, 40).

On the other hand, Healy and Dean (in press) consider that a time related approach is advantageous in that they correlate with the most common projections given for sea level rise (usually to 2100 AD) and that coastal developments are rarely, if ever made to be abandoned. Moreover, the authors consider it more likely that a development will be redeveloped and upgraded over time.

This uncertainty requires the practitioner to ensure that any final determination of hazardous areas is not overly sensitive to the effect of time related extrapolations and assumptions.

10.2 TYPES OF ASSESSMENT TECHNIQUES USED

In general, the range of methods that have been applied to coastal hazard determination can be summarised as being:

1. Quantitative and Empirical. These techniques rely of the collection of data which is fed into a formula to determine the width of land which is subject to coastal hazards of varying degrees or over various time frames;

2. Combined Qualitative-Quantitative These techniques do not rely on the application of empirical formula, at least in their final determination. They often seek to assess the vulnerability of a coastline based on the geomorphic units present, and human influences, some of which will be more vulnerable than others.

The methods set out in detail in Appendix 2 have been provided by four practitioners in the field of coastal hazard management in New Zealand. They are set out as they represent both tested approaches towards hazard assessment and novel techniques, and have been reviewed in published journals and books, and the Planning Tribunal/ Environment Court. Table 1 provides an overview of the techniques assessed, in terms of their predominant factors.

The purpose of this section is to reflect the current state of knowledge on techniques in New Zealand, and present these as optional approaches towards hazard identification. Some of the approaches are more suited to some places than others (for example some of them are related only to cliffs, some others are related only to coastal beach systems and some are more data intensive than others).

10.3 HOW SIGNIGFICANT ARE THE RESULTS?

Regardless of the technique used in any specific situation it is advised that the identification of physically derived hazards should only be part of a proper hazard assessment as set out in Figure 1. It should also be recognised that if areas are defined as being hazardous, that any such definition must recognise the inherent uncertainties which accompany any coastal hazard assessment. In other words "false precision" should be avoided.

Even when a coastal hazard "zone" is determined, there is still no guarantee that within the planning time frame that the coast in question could not be severely affected by a series of destructive storms capable of removing the frontal dune and sand reservoir, or some other coastal hazard, and placing the development at peril (Healy and Dean (in press)). Neither can it be guaranteed that having imposed a setback line, substantial progradation (short or long term) creating new land might not occur, although such an outcome would generally be positive.

Healy and Dean (in press) and Healy (1993) make clear that a Coastal Hazard Zone clear of buildings and development and in a natural state does not on its own constitute a "magical" safety zone immediately on one side of it, and a zone of "total hazard" or impending destruction on the other. Rather it is a line on the ground beyond which, on the balance of evidence, and in the light of scientific knowledge of the moment, it would be prudent to restrict (not necessarily completely avoid) development. Indeed, Kirk (1999) points out that it may be spurious to think of a hazard area as being a zone totally void of any human development or use. For example, recreational uses would be appropriate in a hazard zone. Furthmore, uses such as relocatable surf lifesaving facilities may also be appropriate.

The use of any method to assess the spatial extent of a hazard area raises the issue of the "accuracy" of the setback calculations and the ultimate delineation of the line on the ground (Healy and Dean (in press)). All quantitative methods work from two dimensional profiles, vertical photographs and other one or two dimensional data, and either extrapolate or interpolate that data between points. While each variable is more or less independent of the others, Healy and Dean (in press, 20) point out that to *"to expand great effort to try to refine a 50m setback by say 3m is to assign greater* *accuracy to the calculation than it merits…It is preferable to be conservative in philosophy and designate an appropriately wide zone. In delineating the CHZ it is, therefore, better to err in the direction of too much sand in the coastal reserve than too little. It is not in the interests either of the people who in good faith buy into such developments, or of ethical developers and concerned local authorities, for the developers or local authorities to take risks."*

Table 1.
Comparison of Technique

	Emperical Equation	Non-Emperical	Short Term⊗	Long Term⊗	Human Devpt	⌉S.L. Rise	Safety Factors	Geomorph Features	Multi Zones	GIS & Digital Tech (incl models)
J.G. Gibb	4	8	4	4	4✍	4	4	4	4	4
T.R. Healy	4	8	4	4	4✍	4	4	4🕮	4	4
R.M. Kirk, M.Single, P. Kench (ed)	8	4	4🕮	4🕮	4✍	4🕮	8	4🕮	4	4
Tonkin and Taylor	4	4	4	4	4✍	4	4	4🕮	4	4

<u>Key</u>

4	Specifically Included
4	Included, But Not The Primary or Only Technique
8	Not Included or Only Very Limited Application
4🕮	Empirical Information Included but Not Incorporated in a Unifying Formula
4✍	Non-Empirical Information Included

PART V

11. ACTION 3: STRATEGIC IMPLEMENTATION

The information collected in the Coastal Hazard Directory (Action 1), and on techniques (Action 2) provides the foundation material for the assessment and identification of coastal hazards in the Auckland region. The cost of assessing the entire coastline of the region for coastal hazards means that a more strategic approach to the issue needs to be adopted. Those parts of the coast, which are likely to be subject to hazard, should be given greater priority. Potential sites also need to integrate this with an assessment of the priority of sites in the region for other coastal management programmes, such as wave monitoring and modelling, beach profile monitoring and CoastCare. By doing so, the ARC is able to focus on those coastal areas where the strategic needs of all four of these programmes concur, thus yielding the greatest benefit from the collective data, wisdom and outcomes that can be achieved.

Table 2 presents the result of a prioritisation exercise to determine those sites where focus will be placed by the ARC in the coming years. The table determines priority on a simple scale of 1-3 for each attribute. The various scores are added for each site to give an overall score. The lower the overall score, the higher priority the site has (i.e a site with a score of 4 would have the highest priority, and a site with a score of 12 would have the lowest priority). However, all sites on the table have a general priority greater than other coastal areas in the region.

Ranking for coastal hazards was undertaken on the basis of several criteria. These were:

- Can the site reasonably be considered hazardous, either now, or as a result of anticipated urban growth?
- Does the geomorphology of the site, and the current and future level of development suggest that coastal hazards could be a significant management issue in the near future?
- Is the site reasonably representative of a type of coast within the Auckland region, such that other resource managers could make use of the assessment to determine the best technique and approach in other similar sites?
- Does the site present regional opportunities in terms of promoting hazard resilience?

On the basis of these criteria, a series of sites have been identified as being of a higher priority for coastal hazard assessments within the next 5 years. The table **does not** imply that those sites listed are the most hazardous coastal sites in the region. They are sites where the greatest benefit can be accrued from coastal hazard assessments and which may act as useful examples to follow.

The ARC will take the lead role in the assessment of hazards at these sites, however the speed at which these assessments are undertaken, will depend on the degree of assistance from the relevant Territorial Authority for the area. It may also depend on the timing of development proposals in these areas. Should comprehensive development proposals occur, the ARC will promote the implementation of comprehensive coastal hazard assessments for those areas, in accordance with this strategy, the pRPS and the pRP:C.

12. SITE IDENTIFICATION[1]

The sites identified as being of the highest priority for hazard assessment are described below, and are illustrated on the maps attached as Appendix 5.

Onetangi Beach, a 2 kilometre Holcene beach on the northern side of Waiheke Island and probably the closest east coast surf beach to central Auckland. The beach had an extensive natural dune system reaching as far as 500 metres behind the beach in places prior to development in the early 20th century. Development has been in a ribbon pattern, primarily determined by the construction of a single access road parallel to the shore. The road traverses the former foredune, and its construction most probably was the prime cause of the loss of dunes. In more recent years accelerated erosion and a concern for the future of the beach has resulted in the development of a CoastCare group, and the implementation of an intensive coastline monitoring programme by Auckland City Council.

[1] The report commissioned from Tonkin and Taylor Limited has reviewed these sites in terms of how they represent the types of coastal landforms in the Auckland region, and the likelihood that some of the sites might be more or less sensitive to site specific factors which would limit their applicability. The report notes that there is only one Waitemata group sandstone/mudstone site (Fort Tamaki) and one in Tauranga group material (Te Atatu). Tonkin and Taylor Limited recommend that expansion to further examples of these geological types in the future is advisable. The report also recommends carrying out an assessment of the overall rates of regression for the entire regional coastline.

Maraetai Beach- a shell and sand low lying beach partially sheltered by Waiheke Island. Wave fetch is limited as is water depth, so that the area is not affected by deep water ocean waves. However, Maraetai is still occasionally subject to storm surge related inundation and erosion. Residential and commercial developments are located relatively close to the foreshore, such that the risk from storm related coastal hazards is greater than if there was a more significant set-back. The area is typical of many semi-sheltered coastal locations around the Auckland coast, where typical conditions are sheltered and calm, but storm conditions can leave to more significant effects;

Fort Tamaki - over 11 Hectares of Crown owned land south of Takapuna Beach. The area has been variously used by the Army and the Navy since 1886, and the level of development within is limited to a collection of brick and concrete barrack blocks constructed behind defensive earthworks, and underground tunnels and gun emplacements (Campion; 1998). Geologically the area is typical of eroding Waitemata coastal cliffs and as such has been chosen to be representative of the North Shore coastal cliff environment, while also being made simpler by the lack of residential development. It is recognised however that each section of coastal cliff is relatively unique in terms of specific geological conditions, such that any quantitative assessment of hazard areas in one area is likely to be different from any other;

Te Atatu Peninsula - rolling land under development in the Upper Waitemata Harbour. The peninsula has been formed by rising Holocene sea levels, and is bound on one side by the Whau River and on the other by the Henderson Creek. The peninsula is typical of Waitemata Harbour estuarine coastlines. It is composed of relatively narrow shell and fine sand beaches interspersed with low (2-10m) coastal cliffs composed of Waitemata sandstone/mudstones as well as isolated lenses of Taupo volcanic material which is very soft and plastic. Much of the eastern side of the Peninsula is presently being developed for residential dwellings;

North Shore Beaches - these are typically pocket beaches separate from each other by Waitemata sandstone headlands. The beaches tend to be between 0.5 and 2 kilometres long, usually with a small local stream egressing across the foreshore at the southern or northern end. The beaches often front a small Holocene coastal flat. These areas, and the land atop the cliffs which separate them comprise some of the most intensive coastal residential development in the region. There is only very limited understanding of the representative coastal processes and resultant coastal hazards of these beach systems. A representative beach would be chosen from amongst them;

Long Bay - a headland enclosed beach on the northern limits of metropolitan growth for the North Shore. It is backed by a regional park, and has very limited infrastructural development. Its main sources of sediment is still erosion of Waitemata sandstone headlands, however it is slightly more exposed to the north than other North Shore beaches. As a regional park, the beach forms a useful control site to compare an undeveloped east coast beach system with more developed situations to the south. Long Bay is currently monitored with cross shore beach profiles.

13. INTENDED OUTPUTS FROM COASTAL HAZARD ASSESSMENTS

The development of coastal hazard assessments for each coastal unit identified in Table 2 will require the collection of preliminary data and information. From Table 2, it will be apparent that much of this information will be collected in other coastal management programmes by the ARC (e.g wave and profile data) and also by other organisations. A joint approach to some data collection will be encouraged between the ARC, TLA's, developers, consultant and local residents.

It is intended that all this data, along with the hazard assessments which derive from them, will be integrated to form a "State of Coastal Knowledge" report for each coastal site. Any further information, data or knowledge which is gathered (such as through university thesis research, coastal permit applications etc) will also be included. As each site is prepared for a coastal hazards assessment, a full evaluation will be made of the data which is available for the site (using the Coastal Hazards Directory). At the same time, the most appropriate technique to assess the extent of hazards in the area should be determined. These two actions will allow the identification of information gaps (such as further expert evaluation, process and calibration data, cross shore profiles, aerial/ GPS/GIS maps, wave hindcasting data etc), which can then be gathered to enable a full and proper hazard assessment to take place. The overall output for each coastal area should therefore follow the broad process identified in Figure 1, and would include:

- an identification of the physical processes operating at the site, including waves, currents, tides, winds, hydrology and hydraulics, storm characteristics, and morphodynamics;

- an assessment of the human dimensions of the area, including the type of development, the human activities in the area, provisions of relevant district and regional plans, cultural and community significance, economic values and the structures present;

- the identification of the dimension of the hazard in terms of contemporary physical processes, human influences on the hazard, an identification of the hazardous sites, and an estimation of future charges in hazardous areas.

The final stage, and the ultimate output from this process should be the development of a site specific coastal management strategy to avoid, remedy or mitigate the coastal hazards present or potentially present.

The purpose of this is to bring together, into a useful and valuable resource document, all the available information, data, knowledge and wisdom on those strategic and hazardous parts of the Auckland coastline, and make it available to local authorities, landowners, consultants, planners, engineers etc. This document will then serve as a companion to the ARC Coastal Erosion Management Manual (CEMM). This will allow the above groups to make long term hazard avoidance and mitigation decisions, and also allowing them to make informed and sustainable decisions in terms of shorter time scale erosion management issues.

The ultimate purpose of coastal hazard evaluations is to meet the statutory requirements of the Resource Management Act, and to avoid or remedy coastal hazards. This inevitably means that coastal hazard information should become an integrated part of the decision making process, when it is known that existing or proposed use and development is located in an area subject to hazard. “There is a long-standing precedent in New Zealand regarding the use of coastal hazard zones to guide land use in areas subject to coastal hazards” (Kay et. Al., 1994).

For other regions and districts in New Zealand, this has meant that hazard zones are assessed using the techniques set out in Appendix 1, and that information becomes a part of the district planning process. Examples of the this process can be seen in the district plans of Tauranga, Gisbourne, Opotiki, Whangarei and the Far North. This has also occurred in some cases in the Auckland region, but not in an regionally consistent manner. A useful example is the operative Hauraki Gulf Islands district plan, prepared by Auckland City Council.

PART VI

14. CONCLUSIONS

This Coastal Hazards Strategy has been developed in order to make progress towards meeting statutory requirements in terms of promoting sustainable coastal hazard management. The objectives of the strategy are related to the directions in the Resource Management Act, the NZCPS, the RPS and the pRP:C. It also provides more detail on the intended outcomes for each coastal hazard assessment, and sets in place a series of actions in order to fully meet the policy directions which have been established. These actions will assist in ensuring that the hazard management model set out in Figure 1 is applied to all parts of the coast where hazards may require management

The major actions have been to:

- Develop a Coastal Hazards Directory;
- Collate and assess a range of coastal hazard identification techniques applicable to the Auckland region; and
- Detail a strategic approach to hazard assessment throughout the region.

In doing so, the strategy has also provided detail on other related ARC programmes. Users of the Coastal Hazards Strategy should make use of these other information sources when establishing a management framework for coastal hazards. The strategy has also identified those technical areas in which there is presently uncertainty and debate. While all these issues are still open to varying views in the scientific and professional literature, it is important that those involved in coastal hazard management are aware of the range of views on these matters, so that they can make informed judgements.

The strategy is not an end in itself. It is a blueprint for action, and a reference on ways in which to achieve better management of the hazards inherent when human development occurs in the coastal environment. Sustainable outcomes will only be fully promoted when these guides and actions are implemented in a coherent and consistent manner along the coastline of our region.

APPENDIX 1: HISTORY, TECHNICAL INFORMATION AND RELATED RESEARCH AND INVESTIGATION PROGRAMMES

A1. History of Coastal Hazard Management in New Zealand

Prior to the enactment of the Resource Management Act 1991, the prevention and mitigation of coastal hazards was primarily the responsibility of the National Water and Soil Conservation Authority (NWASCA) and the 20 catchment authorities serviced by them throughout New Zealand. Both the Soil Conservation and River Control Act 1941 and the Water and Soil Conservation Act 1967 gave these authorities a number of discretionary powers to prevent and mitigate coastal hazards (Gibb, 1998).

In terms of coastal planning, the Town and Country Planning Act 1977 gave territorial authorities the power to identify areas vulnerable to natural hazards in regional planning schemes, district planning schemes and maritime planning schemes.

In the 1970's there was no New Zealand government policy on the management of natural hazards. Existing policy mostly covered the issue of protection works. During this period, NWASCA was mostly informed about natural hazard problems after they had occurred. For most areas, little if any information or data was available on natural coastal processes. Most planning and management was therefore reactive in nature (Gibb, 1998). Consequently, new coastal subdivisions were often located in coastal areas where a previous coastal development had been damaged or even destroyed by the sea. The Auckland settlement of Omaha as well as the township of Hokitika and the settlement of Ohiwa Spit provide a number of examples (Gibb, 1998).

In the late 1970's and early 1980's, the concept of coastal hazard management began to gain acceptance. Various different approaches towards the concept were developed. Some relied on the application of empirical formulae to determine a time-related distance from the shoreline within which the land was considered to be subject, or potentially subject to hazards. Such approaches tend to lead to the development of "coastal hazard zones/areas". The two major proponents in New Zealand of this approach are Dr J.G. Gibb and Professor T.R Healy. These techniques have been applied mainly on east coast sandy beaches in the North Island, and especially in the Bay of Plenty, Gisbourne, Coromandel and Northland areas. Some other areas have been investigated including the Kapiti coast and Hokitika. Proponents of this approach state that it does have collateral benefit in terms of preserving the natural character of the coastal environment, which may be captured within the coastal hazard zone (Healy and Dean, *in press,* Healy, 1993, Healy 1997).

Other approaches have looked at the issue in a broader sense, and have applied the concept of coastal hazard management to other morphologies including gravel beaches and barriers. These approaches do not apply only a formula to the issue, but rather seek to work from a series of well established coastal management principles and apply them using informed expert judgement to each particular case. These are based on an understanding of the physical coastal system operating, and the need to protect and preserve essential elements of that system from use and development. These approaches may not necessarily lead to coastal hazard zones, although they do usually result in the identification of *areas* which based upon historical knowledge, contemporary coastal processes and coastal geomorphology, are unlikely to be suitable for sustainable coastal use and development. The major proponents of this approach in New Zealand are Professor R.M Kirk and Dr M. Single. The approach has been applied at locations in the South Island, such as South Brighton Spit, Christchurch and Washdyke Lagoon, Timaru.

Other techniques seek to develop an approach that integrates empirical evaluations with geomorphic observation. In this model, an empirically derived coastal hazard zone is modified after consideration of the coastal geomorphology of the backshore area. In particular, a coastal hazard zone is deliberately identified so to include the entire foredune complex within the zone. This approach has recently been developed and tested at Omaha by Tonkin and Taylor Limited.

A2. Types of Coastal Hazard Processes

Within the Auckland Region the primary hazards arising from these interactions include erosion[2], inundation of low lying areas, land instability (especially in relation to cliffs), storm surge, rising mean sea level, and tsunami. These hazards may occur individually, or combine to create a cumulatively more significant hazard.

An example of an area in the Auckland region which has been exposed to coastal hazards is Omaha Beach. Hazards at Omaha are the result of a combination of human modification to the environment (such as lowering of the foredune), and the onset of extreme conditions. In July 1978, the coastal settlement which had developed on this barrier spit was significantly affected by a cyclone. The storm, and its attendant storm surge caused widespread erosion on the east coast of Auckland. At Omaha, it destroyed the wooden seawall which had been built, and impacted on the adjacent residential development (Figure 2). Other more frequent storms (such as summer sub-tropical cyclones tracking near Auckland) can also cause significant damage and can

[2] In this context “erosion” refers to both shoreline retreat such as is observed by retreat of the dune line, and erosion of sediment from the foreshore leading to lost amenity value.

from time to time make parts of the region hazardous.

There are many other hazardous or potentially hazardous sites within the region. Some of these are low lying coastal flats which have been settled (for example Maraetai), or developed holocene sand spits (for example Omaha, Orewa), significant coastal settlement adjacent to sandy beaches where backshore and dune landforms have been obliterated (for example Takapuna, Milford) or landforms which have been eroded by gradual sea level rise and occasional storm surge (for example Te Atatu).

Storm surge can cause elevated water levels which increase the risk of flood damage. Even in harbours and estuaries (such as the Upper Waitemata Harbour), these can combine with tidal effects and cause extreme water levels (Figure 2). The soft sedimentary nature of many of the coastal cliffs of the region mean that development close to cliffs is often hazardous. While the rate of regression of these features is often expressed in centimetres per year, cliffs often fail in spectacular fashion, yielding as much as metres in single events. The effect of this can be to leave apparently stable and safe dwellings and other buildings in unsafe situations (Figure 3). De Lange (1997) assessed some storm surge scenarios for the Auckland region. He noted that storm surge is due to two processes: adjustments of mean water level caused by changes in atmospheric pressure; and movement of water over the continental shelf due to stress exerted by winds. While the response of water level to pressure changes is relatively slow (2-12 hours), responses to wind stress can be more rapid.

The response of water levels to changes in pressure can be reasonably predicted. The "inverse barometric effect" describes the rise in sea level of about 10mm for every 1mb drop in atmospheric pressure. This change is however affected by coastal geometry, with harbours and inlets causing some changes in this relationship. De Lange (1997) noted that the result of a 1mb drop in pressure in the Waitemata Harbour is a rise in mean water level of 9.5mm.

The effect of wind stresses on water over the continental shelf (sometimes called "wind set-up") is harder to predict. In simple terms an onshore wind blowing at right angles to the coast will cause water to pile up on the coast. This will in turn cause a return current to establish travelling along the seabed and out to sea.

De Lange (1997) recommends a simple rule of thumb which states that the actual storm surge experienced on the coast will be twice the inverse barometric response (e.g a onshore storm with a drop in pressure of 1mb will lead to a 20mm rise in water level).

The major hazards associated with storm surge are coastal erosion due to increased

[3] Shallow Water Wave = a wave whose velocity is a function of water depth. For example the Pacific basin is "shallow water" for a tsunami.

stork wave penetration and flooding of low lying coastal areas. De Lange (1997) noted that storm surge on the Hauraki Plains in 1938 flooded about 35,000 Ha of land as far inland as Ngatea. The total water elevation was about 3m above MSL. The rainfall associated with storms that produce storm surge can also caused flooding which can be exacerbated by storm surged coastal water impeding the discharge of rivers and stormwater systems.

Tsunami describes long period shallow water waves[3] with typical periods ranging from 15 to 60 minutes. A tsunami travels faster in deeper water and may only be 0.5m high. When it travels into shallower water, the tsunami slows down and increases in size. Most tsunami are only about 1m in height when they reach the shore.

The behaviour of a tsunami can vary considerably along the coast, depending on coastal geometry and bathymetry. The effect of the tsunami is also affected by the direction of its approach. de Lange (1997) reported the research of de Lange and Hull (1994) which defined the potential tsunami hazards for the Auckland region as being due to 5 factors:

1. Tsunami Run-up

   This can be expressed either as a vertical height or a horizontal distance. Tsunami crossing the continental shelf decompose into a series of solitary waves, which can reach the shore either as broken or non-broken waves. According to de Lange (1997) all known tsunami affecting the Auckland coast have acted as non-broken waves. Such waves reach their maximum vertical runup on the natural beach approximately equal to the maximum wave amplitude when the wave first reaches dry land.

2. Tsunami Bores

   These are the most destructive tsunami due to the transformation of momentum that occurs as energy is transferred from the wave into still water. This results in high horizontal and vertical turbulence, and increases the wave height. The vertical turbulence is capable of entraining large objects, and in estuaries opposing currents may result in a greater steepness of the wave front and enhanced bore formation (de Lange, 1997).

3. Floating Debris

   Most fatalities associated with recent tsunami are caused by floating debris acting as projectiles under the turbulent force of the tsunami and its associated currents. The tsunami can also caused the dispersal of liquid contaminants such as oil and lighter fuels, enhancing the level of hazard, especially in port and industrial areas.

4. Return Flow and Currents

The current velocities due to a receding tsunami can also be very high due to extreme variations in water level (de Lange, 1997). Most drownings due to tsunami are caused by people being swept out to sea by such processes. The return flow also contains the same risks due to debris and floating projectiles. Such flows are also very erosive, and can lead to complex and unique patterns of currents and waves.

5. Forced Oscillations

Tsunami may force oscillations within enclosed estuaries and bays as energy is reflected off basin walls. This may cause an amplification of the tsunami if the frequency of the wave synchronises with the geometry of the inlet (de Lange, 1997).

The tsunami hazard has a variable probability and a range of magnitudes. The most likely hazardous tsunami event for the region is a far field (originating from a distant source) tsunami caused by an earthquake off the west coast of Chile. Incoming wave heights would be of the order of 1-3m (not including local amplification effects). A far field event from this source would affect both coasts, with historical evidence suggesting the east coast response would be twice that of the west coast. The return period of such an event is about 75 years. Near field tsunami from earthquakes along local faults (e.g Kerepehi fault) or from a volcanic eruption are also possible, although they have considerably longer return periods (4,500-9,000 years for fault related tsunami and 1,000 years for volcanic events).

Sea Level Rise

Changes in sea level have an inevitable effect on human uses of the coastal environment. The geological record suggests that natural changes in sea level occur at very large scales over very long time periods. Fluctuations of over 100 vertical metres in sea level have been inferred from geological records over the past 1.25 million years. During the last glacial period (125,000-10,000 years BP) lower sea levels saw the east coast shoreline beyond Great Barrier Island and the Mokohinau Islands.

As early as 1941, analysis of historical sea levels from Europe pointed towards a gradual rise in sea level (Schofield, 1960). Early analysis of tidal gauge information from New Zealand ports pointed towards a similar trend, although based on a much shorter length of data. Schofield in 1960 analysed the Auckland tide record, and found a sea level rise of 10cm per 100 years on average from 1900 to 1930, and then an accelerated rate of 20-25cm per century from 1930 to 1956. At that time, Schofield suggested that the recorded rise may well have been *"only another minor fluctuation in* *an otherwise fairly stable sea."* (Schofield, 1960,482).

Since that time, further analyses of historic and contemporary sea levels have been undertaken in the Auckland region. Woodroffe, Curtis and McLean (1983) revisited Schofield's work in the Firth of Thames, and refined a model for Chenier ridge development (a landform feature highly sensitive to sea level changes). In doing so they shed more light on late Holocene sea level changes. Gibb (1986) undertook a similar analysis of the Weiti sand spits, which have recorded sea level over the entire Holocene period of 10,000 years. Together these three studies have helped to build a Holocene sea level curve for the Auckland region and for New Zealand.

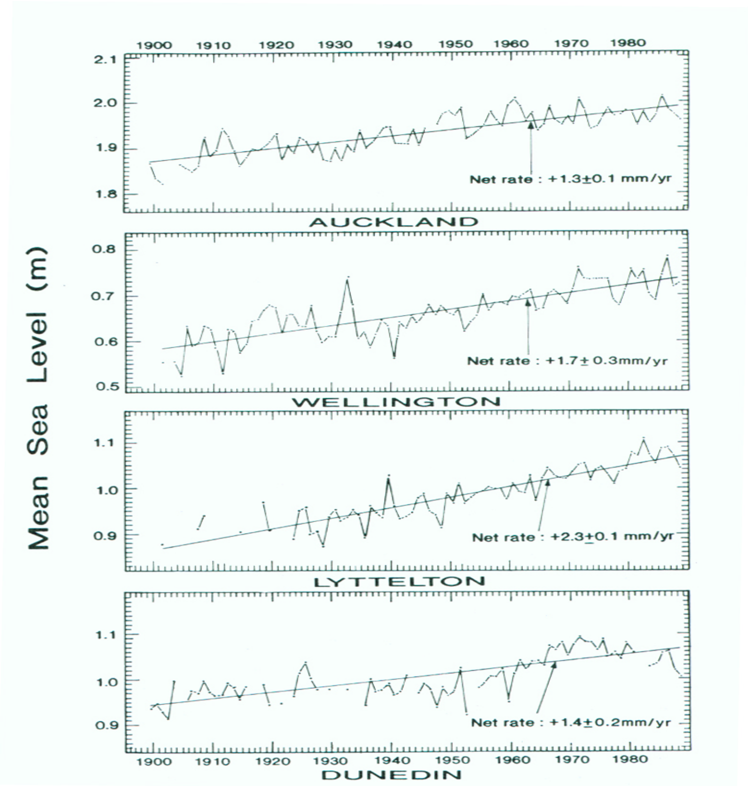
In 1990, Hannah was commissioned by the then Department of Lands and Survey to determine the historical rate and trend of sea-level rise from automatic tide gauges that had been collecting information from the ports of Auckland, Wellington, Lyttelton and Dunedin since 1899 (Gibb, 1991). The results of his worked are reported in Hannah (1990). Hannah noted that the tidal gauge record from Auckland (Queens' Wharf, Waitemata Harbour) has been of a very good quality, with the gauge and records well maintained since 1904. The effect of this is that the Auckland data is less 'noisy' than data from other ports. The recording site is also considered tectonically stable.

Hannah presented data on the annual mean sea levels for the 4 ports. Figure A1 presents the raw digitised data derived by Hannah[4]. The figures show an apparently greater net rate of increase in Wellington, Lyttelton and Dunedin than in Auckland. However, many meteorological and oceanographic parameters directly influence the variations which occur in MSL on a yearly basis. These include factors such as wind stress, atmospheric pressure, precipitation, river discharges, currents, temperature and salinity of the water, and long term periodic lunar tides. Following this analysis, Hannah developed a series of curves which assessed the residual sea level change evident at the four ports. From these, lineal trends in sea level were derived. For Auckland they are reported as an annual rise of 1.3 ± 0.3mm/yr.

In his conclusions, Hannah averaged the rate for all four sites, and reported an apparent sea level rise for the east coast of New Zealand of 1.7mm/yr since the beginning of the 20th century. He concluded that this figure, both in its raw form and when isostatically adjusted, matched very closely the global figures published at that time by other authors.

[4] Figure A1 is taken from Gibb (1991) only due to the greater clarity and detail of the Gibb figure. The figure is in all other respects identical to that in Hannah (1990), in Journal of Geophysical Research, Vol 95, No B8 12,p401

Figure A1.



Plots of the Annual Mean Sea Levels at Auckland, Wellington, Lyttleton and Dunedin

Figure A2.

Destroyed Wooden Seawall, Omaha July 1978

Figure A3

StormSurge, Upper Waitemata Harbour, 1996

Figure A4

Typical Eroded Waitemata Series Cliff, Fort Tamaki, North Shore

Figure A5

Storm Surge During Cylone Drena (January 1997), Maraetai Beach

A3. ARC Environmental Research and Management Programmes

The successful implementation of this hazard strategy forms part of a wider series of programmes run by the ARC, both in respect of hazards within the region, and more specifically on the coast. In terms of the Coastal Environment, there are several concurrent programmes underway. These can be divided into those monitoring physical coastal processes, and those concerned with managing the natural and human response to those processes.

Of the physical processes, the ARC has assessed waves and tides as being the most significant natural physical coastal processes which both shape the character of the coastline, and the ways in which people and communities use and develop it. The response of the coastline to these processes needs to also be measured, so that a cause-effect relationship can be established. To achieve this, the ARC undertakes a coastline monitoring programme, the wave climate strategy and has developed this coastal hazards strategy.

Coastline Monitoring Programme

The Coastline Monitoring Programme maintains a series of cross-shore profiles on thirteeen beaches in the region. These are:

i) Pakiri Beach

ii) Omaha Beach

iii) Long Bay

iv) Muriwai Beach

v) Piha Beach

vi) Brown's Bay

vii) Campbell's Bay

viii) Takapuna

ix) Cheltenham

x) Maraetai Beach

xi) Kawakawa Bay

xii) Orere Point

Cross-shore profiles provide cross- sectional data on the volume of sediment on a beach at a given time. Providing there are sufficient survey lines on a beach, an estimation of total volume changes in the beach can also be made. Surveys also illustrate changes in morphology, such as the growth, maintenance or destruction of berms, bars and dunes. A technique called "excursion analysis" provides a detailed summary of exchanges of sediment in the shore profile by tracking the horizontal movement of different elevations on the profile. Successive surveys allow patterns in beach behaviour to be archived and understood.

The data collected from these sites provides valuable long term data on changes in beach profile and an indication of the dynamic envelope through which the coast oscillates. This provides important information in the potential hazards affecting any development in these, and related areas. It also allows an assessment to be made of the effect of future changes such as sea-level rise, wave attack and storm surge.

Wave Monitoring Programme

The Wave Monitoring Programme recognises the variability and change in some of the factors which affect coastal hazards. The frequency and magnitude of coastal storm events is at present virtually unknown for the Auckland region, and the whole nature of waves in the Auckland region is presently poorly understood. To address this, the ARC has implemented a Wave Climate Strategy. The key component of the wave strategy is the deployment and operation of a directional wave buoy in the Hauraki Gulf (Figure A6). Through deployment of the buoy, the ARC will collect wave data, in order to gain a long term appreciation of the "climate" of oceanic waves which affect the region. An example of wave height data is provided in Figure A9. This understanding will assist the ARC in making decisions on shoreline management, the extent to which foreshore protection works need to be undertaken, and also the extent to which deep water waves impact upon the coast and create hazards.

Wave in more sheltered locations, especially within harbours and in the inner Hauraki Gulf are also currently being assessed. This is since the deep water waves measured by the wave buoy have little or no effect in those parts of the region which are significantly sheltered from ocean swells (although most areas are affected to a greater or lesser degree). The ARC, in conjunction with NIWA, are developing a "Wave Hindcasting" programme. Wave "hindcasting" means predicting waves for a given period in the past based on the known wind conditions for that time. Once a sufficient number of wind and wave conditions are correlated for a site it is then possible, based on that data, to make reasonable forecasts of wave conditions for any given wind related event. This programme will allow wave climates at discrete sites on the coast to be calculated by following a number of steps. These are:

a) From historical wind data for the whole region, develop a computer based model of winds for the Auckland region (Atmospheric Boundary Layer Model- ABLM),

b) Using the ABLM as input data, determine a historical wind climate for a particular site of interest,

c) Use the local wind climate data and site specific bathymetric information, to determine the wave characteristics which would arise in that location, using wave generation models such as "SWAN"

An example of the output of the wave hindcasting process is illustrated in Figure 7. It shows the wave heights for the Tamaki Strait area modelled by the numberical model SWAN from wind data on 14 January 1999 at 4pm.

Figure A6.

Deployed Directional Wave Buoy, Mokohinuau Islands, 1998

A4. Other Data useful for the Hazard Strategy

An example of the output of the wave hindcasting process is illustrated in Figure 7. It shows the wave heights for the Tamaki Strait area modelled by the numerical model SWAN from wind data on 14 January 1999 at 4pm.

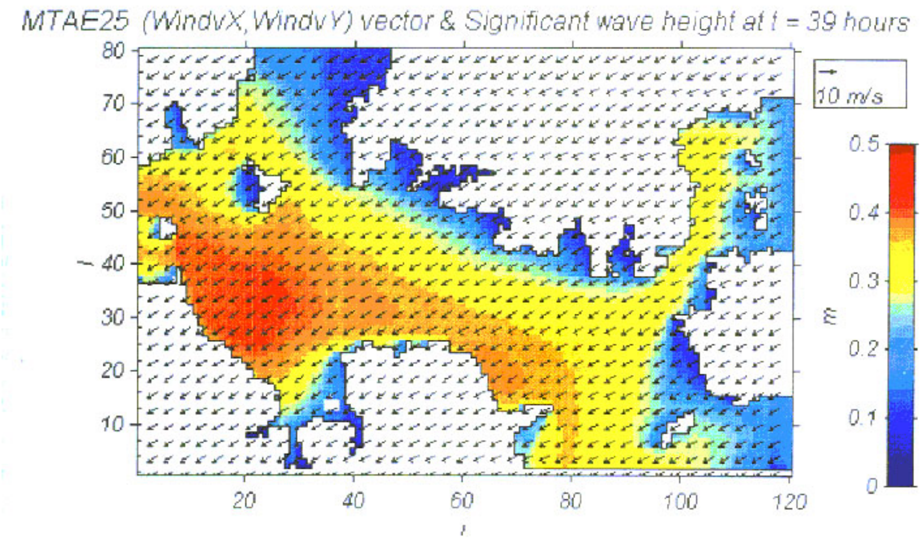
While sea-level recorders have been in operation at the Port of Auckland since 1899, and the Port of Onehunga for a similar time period, their location within tidal estuaries has made their usefulness limited. The length of continuous high quality data from these has also been variable.

The value in recording sea-level is that it contains 2 signals:

i) tidal amplitude produced principally by the gravitational effects of the sun and the moon;

ii) storm surge effects caused by the inverse barometric effect and wind set-up.

Figure A7.



Output from the SWAN Wave Hindcasting Model

Until now, determining the magnitude of storm surge in the Auckland region has relied on empirical equations (refer Frisby and Goldberg; 1981), or by using the information provided by the Auckland and Onehunga tidal gauges. While they remain used by many practitioners as a first order estimation of storm surge magnitude, The equations of the kind used by Frisby and Goldberg are now rather outdated and more modern methods can be applied (Kirk, 1994). Where possible, real data of the kind described below should be used.

NIWA has embarked on a programme of expanding the coverage of sea-level recorders around the New Zealand coast, so as to gather better quality information on changes in sea level associated with both tides and storm surge. Sea level recorders have the advantage of providing an actual measure of sea level. As tides are a deterministic (i.e they can be precisely predicted), tidal effects can be removed from the record to leave storm surge effects. Nine additional recorders are being deployed around the New Zealand coast, including one at the Mokohinau Islands (east coast) and one at Anawhata (west coast). Sea-level recorders will allow the direct measurement of storm surge. When the predicted tidal amplitude is removed from the sea-level record, it is possible to determine the frequency and magnitude of storm surge. NIWA has also developed a statistical package which allows the determination

[5] All quantities are in mm above Mean Sea Level. SL is the actual sea level. SS is the storm surge, IB is inverted barometer (the effect of barometric pressure alone) and Tide is the maximum tide height. The difference between SS and IB is an indication of the effect that wind set-up had on the storm surge.

of the frequency and return period of such events, based upon historical sea level records (EXTLEV). At present the amount of sea level data from the Waitemata which is in a form suitable for inclusion into the EXTLEV program is very short (8 years). Analysis of this data using EXTLEV shows that the 1% Annual Exceedence Probability (AEP) sea level for the Waitemata Harbour is estimated to be 3240mm ± 200mm above MSL (1770mm).

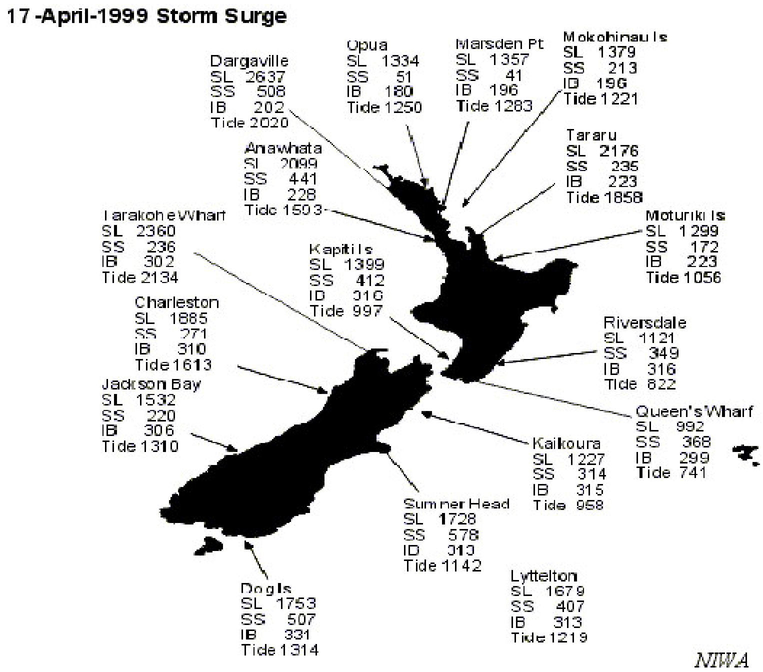


Figure A8.

Storm Surge on the Coastline of New Zealand, 17 April 1999[5] (NIWA)

Figure A9.

Wave Height Distribution, May to December 1998

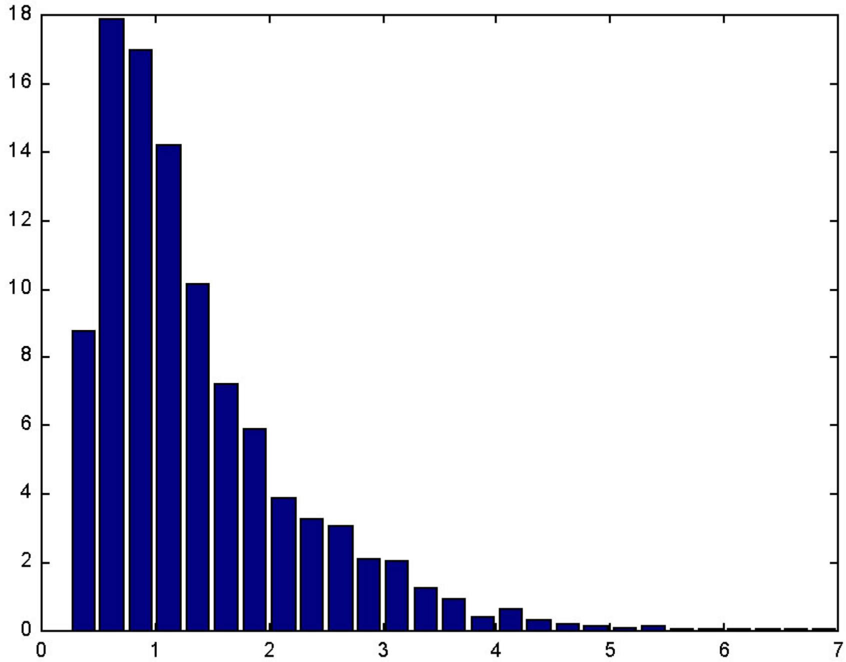
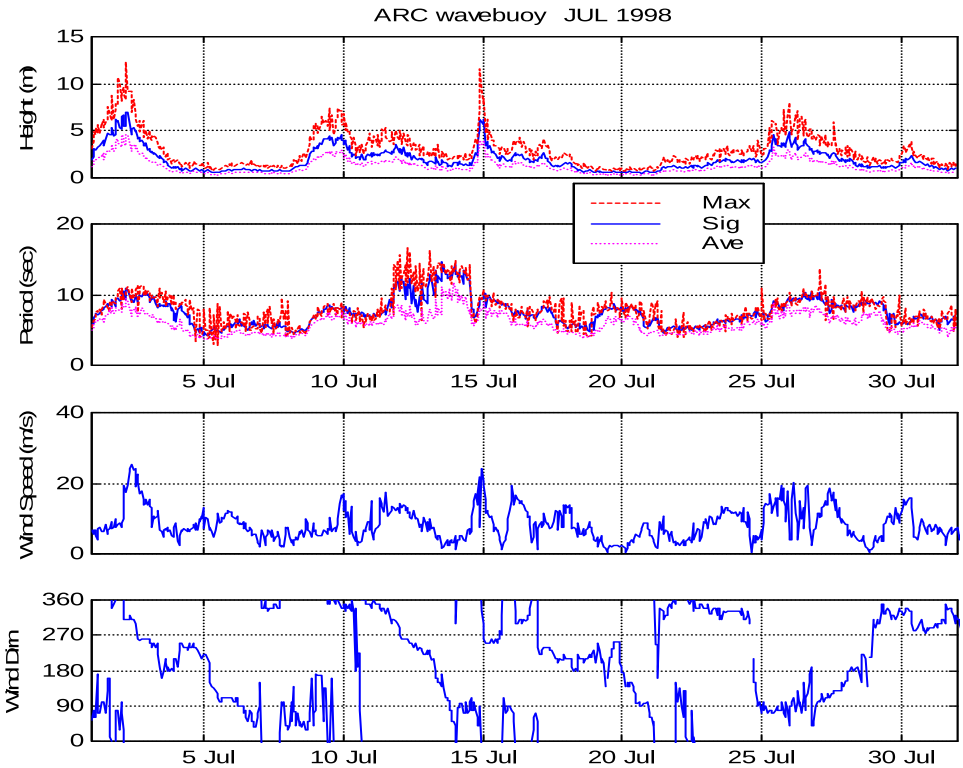


Figure A10.



Wave Height, Period and Wind Direction and Speed, July 1998

A5. Erosion Management- A Subset of Coastal Hazard Management

The management of coastal hazards can be controversial, with complexities and conflicts of interest related to the high public and private values which exist in the coastal environment. To date, risk to coastal development or private property have typically been managed by attempting to modify natural coastal processes and shoreline behaviour- particularly with the use of shoreline armouring devices to control erosion. While in some situations these are appropriate and sustainable responses to coastal hazards, there are many situations where they are not, and more effective and sustainable means or methods should be found. To assist with the appropriate choice of erosion management techniques, the ARC has developed a "Coastal Erosion Management Manual (CEMM)". A summary of the contents of the CEMM is set out in Appendix 4.

The CEMM and this Coastal Hazards Strategy are very closely related in terms of the ARC's overall coastal management programme. The hazard strategy is aimed at promoting the avoidance of coastal hazards where-ever possible by early identification of those parts of the coastal environment which may not be sustainable for certain types of subdivision, use and development. The CEMM provides advice where coastal development already exists, or where other constraints limit the flexibility of development options, such that erosion protection measures need to be considered. These two resource documents therefore make a significant contribution towards the "avoid-remedy-mitigation" continuum set out in Section 5 of the RMA.

The primary driving force for the development of the CEMM is the resource consent process. This in turn is brought about by the desire of people to live and develop resources in close proximity to the dynamic interface between land and water. The ARC has determined the need for timely advice and direction to be made available:

- To assist present and potential users and occupiers of the coastal environment in understanding the nature of coastal erosion and identifying options available for the management of such circumstances.

- To assist those responsible for management of coastal erosion in reaching informed and balanced merit-based decisions.

- To ensure there is integrated and sustainable management of the coastal environment.

- To ensure efficiency in the preparation and processing of resource consent applications, minimising the processing time for applicants. Applications for coastal erosion measures invariably do not consider alternative options, do not provide all the necessary information to process the application, and/or propose inappropriate solutions for the circumstance.

- To provide specialist knowledge to the public who may have cause to enquire about coastal erosion matters.

- To ensure that coastal erosion management works are appropriately designed, constructed and maintained. Inappropriate efforts to manage coastal erosion don't always lead to sustainable solutions, and can cause other adverse effects (such as visual).

- To assist ARC and Territorial Authorities (TLA) personnel in processing consent applications.

The Manual promotes a process of identifying and confirming the coastal erosion "problem", determining its cause, understanding the environmental context of the erosion, and then assessing a range of erosion management options. These are assessed in order of priority from non-structural to soft structural to hard structural. Once a range of options is developed, they are screened through an assessment of effects to the selection of a preferred option. The preferred option is then assessed in detail, costs are considered and action is then taken.

The manual should be applied by people who are involved in the selection, design, maintenance and regulation of coastal erosion management options including:

- owners and developers of coastal areas;

- resource managers, community groups and government agencies with an interest in coastal areas; and

- engineers, planners and landscape architects representing the above groups.

The manual will also be of use to public who would like to make informed decisions concerning coastal erosion management.

APPENDIX 2: COASTAL HAZARD EVALUATION TECHNIQUES

1. QUANTITATIVE AND EMPIRICAL

1A. J.G. Gibb

Gibb has been involved in coastal hazard risk assessment in New Zealand since the 1970's. In September 1998, he prepared a report for the ARC entitled "A Personal Contribution to Coastal Hazard Risk Assessment in New Zealand." The report sets out the key influences on coastal hazard management (as seen by Dr Gibb), important precedent cases which have affected coastal hazard management in New Zealand, positive initiatives taken in the 1980's and their application, applications during the 1990's (including the role of GIS as an important analytical tool) and a summary.

In his Summary, Gibb sets out some concluding thoughts on the purpose and utility of Coastal Hazard assessments. He lists these as:

"1. The ultimate goal for all Coastal Hazard Risk assessments is to make the information available to the general public through the statutory

planning process by including Coastal Hazard Risk Zones and appropriate policies in both Regional and District Plans to manage subdivision, use and development of the New Zealand coast.

2. *Coastal Hazard Risk assessments should involve suitably qualified and experienced personnel with an added flare for public consultation, information transfer and successful presentation of expert evidence at Hearings and before the Environment Court of New Zealand.*
3. *The findings of this report provide sufficient information for Auckland Regional Council and other Regional Councils to collaborate with the Territorial Local Authorities in their regions to develop Coastal Hazard Mapping Programmes with an Action Plan for Coastal Hazard Risk assessments for priority areas.*
4. *The Coastal Hazard Risk assessment techniques including the GIS computer model described in this study can be applied to any coastal area in the Auckland Region or other Regions, with respect to the common natural coastal hazards of erosion, flooding and landslip."* (Gibb: 1998, 50)

When discussing key influences, Gibb (1998, 2) notes that *"like most countries, New Zealand has a legacy of siting coastal development in areas subject to significant adverse effects from natural coastal hazards, particularly sea and wind erosion, sea flooding and coastal landslip."* He also notes that such development may be at risk from damage and destruction. According to Gibb, the most common responses to these events are the construction of hard engineering structures such as seawalls, rock revetments and groynes, which are expensive to maintain and construct, and often cause permanent damage to the beach profile.

Gibb considers that a key factor in this has been a lack of understanding of the influence of the foredune or primary beach ridge. Development has encroached onto these areas, and has consequently reduced the ability of these features to function in protecting the coastal hinterland.

In assessing the development of coastal hazard policy, legislation and case experience over the last 25 years, Gibb (1998,1) concludes that the overriding philosophy must be *"prevention is better than cure"*

In his report, Dr Gibb sets out in detail a set of cases which have contributed towards coastal hazard management using his approach. These include:

- Hicks Bay. In this location a proposed subdivision was declined planning consent due to the hazard posed by the frequent migration of the Wharekahika River. According to Gibb, a small residential subdivision at the northern end of the bay was actually destroyed in 1974. In determining the appeal relating to the proposal, Judge Turner ruled that that land *"is at present unsuitable for residential subdivision because of its liability to erosion through sea and river action."* (T.P McCarthy & Ors v. Waiapu C.C., 468/71, *reported in* Gibb; 1998, 6)

- Omara Spit. Located on the eastern Coromandel Peninsula, the land was approved for residential subdivision in 1968, with development proceeding from the base of the spit northwards. The second stage of development was determined on appeal to the Town and Country Planning Appeal Board. Gibb reports the findings of Judge Turner as including a recognition that a buffer zone needed to be provided to accommodate the effects of coastal hazards and that the *"preservation of the natural character of the coastal environment"* was *"equally as important as provision in case of erosion"* (The Physical Environment Assoc. of Coromandel Inc. v. Thames-Coromandel D.C., 782/75 *reported in* Gibb; 1998,7) the Board imposed a building prohibition within 100m from the seaward toe of the foredune, 40m of MHWM on the estuary shore and 900m on the spit "head" (distal end of the spit).

- Peka Peka. Gibb describes a proposed development within 20m of MHWM on the Kapiti Coast. In his summary, Gibb notes that the proposal was advertised at the same time that a storm destroyed one house and threatened 30 others to the south of the proposed development. As a result, a 50m buffer was included in the District Plan in 1978, and the proposed development went before Appeal in 1979. Gibb presented evidence that a Coastal Hazard Zone of 90 to 100m was required to protect the foredune complex. After the Tribunal's decision that *"no subdivision is to be permitted between 50m and 90m of the seaward vegetation line if such subdivision intrudes into the line of the inland toe of the main foredune"* (MWD & Ors. V. First NZRDC & Horowhenua C.C., W 18/80 *reported in* Gibb; 1998, 8), the Council resolved the matter by designating a foreshore reserve of 70m width. Gibb notes in his report that a well vegetated and stable foredune complex now exists in the area.

- Mount Maunganui. Gibb undertook a coastal hazard assessment for a section of the Mount Maunganui coastline in 1980. The result was a *"100 year hazard line"* being a *"straight line approximating the position of the inland toe of the foredune"* and ranging in distance *"from 63 to 83m inland from the 1981 seaward toe of the foredune generally averaging about 70m."*(Gibb; 1982a *reported in* Gibb; 1998,8). As with the above examples, this was considered on appeal to the Planning Tribunal, and accepted as being reasonable given the nature of the environment and the likely risk involved for development any closer to MHWM.

Gibb also sets out the approaches which he helped to develop for the Queensland Beach Protection Authority in the 1970's. The reader is referred to pages 8-10 of Gibb (1998) for detail on these techniques. Techniques specifically developed by Gibb for New Zealand are set out below.

Between 1979 and 1980, Gibb conceived, developed tested and standardised Coastal Hazard Mapping (CHM) techniques for NWASCO (the National Water and Soil Conservation Authority) from a pilot study in the Waiapu Counry, East Cape. For both landslip and erosion CHZ's (coastal hazard zones) were calculated by empirical methods (Figure A1).

In these techniques:

CHZ = (R x T) + S

CHZ = (R x T) + F

Where T = Assessment period of 100 years

R = Long term trend of erosion or accretion (m/years)

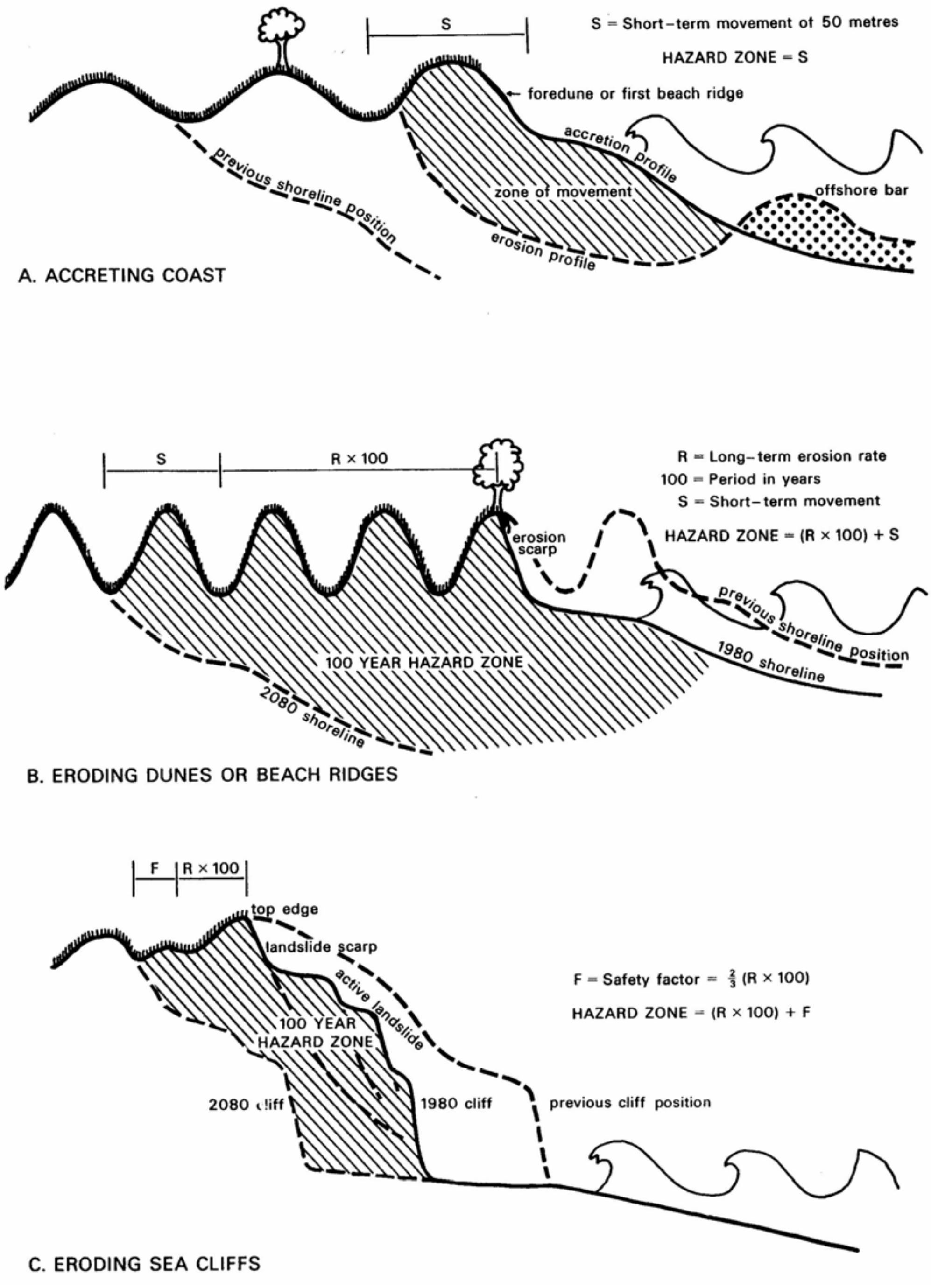
S = Extent of short term shoreline movements (metres)

F = Safety factor of two-thirds the product (R x T) for landslip.

For flooding, Gibb used a quantitative appraisal of the various factors that combine to determine SWRU (Storm Wave Run Up) elevations, adapted from Frisby and Goldberg (1981). These various factors are shown in

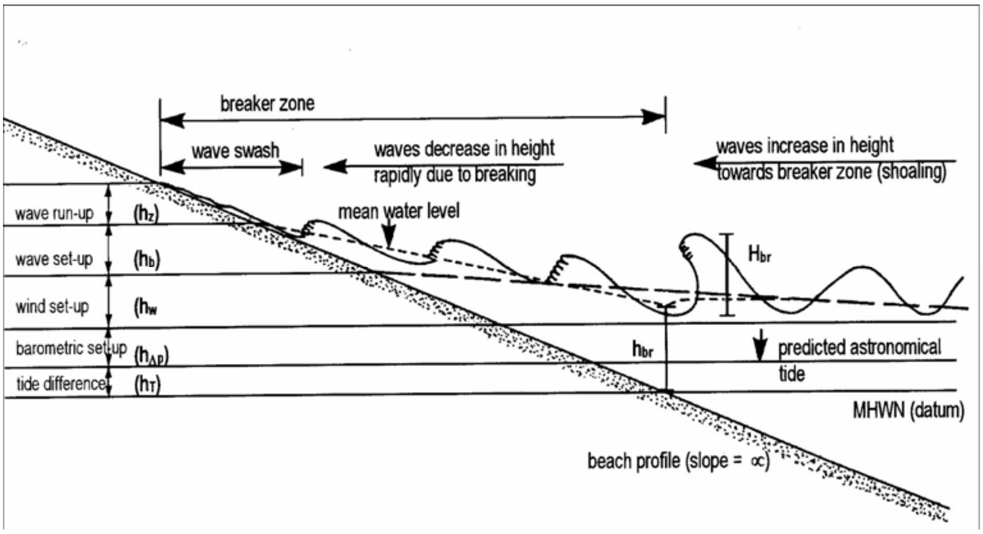
Figure A2, and are described more fully in Gibb (1998).

Figure B1.



Diagrams showing the methods used by Gibb to assess coastal hazard zone widths along the Waiapu coastline for accreting coasts (a), eroding sand dune and gravel beaches (b) and eroding sea cliffs (c) (Gibb, 1998)

Figure B2.



Schematic Diagram Showing the Components of SWRU (Frisby and Goldberg, 1981 in Gibb, 1998).

Between 1982 and 1983, Gibb led an investigation to determine a coastal hazard zone for Pauanui Beach on the eastern Coromandel Peninsula. As well as taking into account the factors assessed at Waiapu, the assessment also included a factor to allow for erosion from accelerated sea-level rise in response to an enhanced "greenhouse effect". The Pauanui assessment took into account the following factors:

X = Erosion from predicted sea-level rise (m/year)

R = Long term historic erosion-accretion rate (m/year)

T = Planning Horizon of 100 (years)

S = Maximum short-term erosion-accretion fluctuation (metres)

The width of the CHZ was calculated as follows:

CHZ = (X + R) T + S

Factor X was calculated by Gibb using the Bruun Rule (Bruun 1962, 1983). The rule states that *"for a shore profile in equilibrium, as sea level rises, beach erosion takes place in order to provide sediments to the nearshore so that the nearshore seabed can be elevated in direct proportion to the rise in sea-level".* The equation used to determine this is:

$$X = \frac{la}{h + d}$$

Where

a = rate of sea level rise (m/year)

l = distance to closure depth from the dune crest (metres)

h = Height of dune crest above MSL (metres)

d = Average closure depth below MSL (metres).

Figure A3, illustrates the two-dimensional Bruun Rule. A detailed account of the Pauanui assessment, and others undertaken by Gibb in the 1980's, is set out in Gibb and Auburn (1986) and Gibb (1998). Work undertaken by Gibb in the 1990's has focused on the development of a three step process towards identifying and quantifying natural coastal hazards. These steps are:

1. Qualitative reconnaissance survey of natural coastal hazards;
2. Identifying initial areas sensitive to coastal hazards;
3. Identifying specific coastal hazard risk zones.

Figure B3.

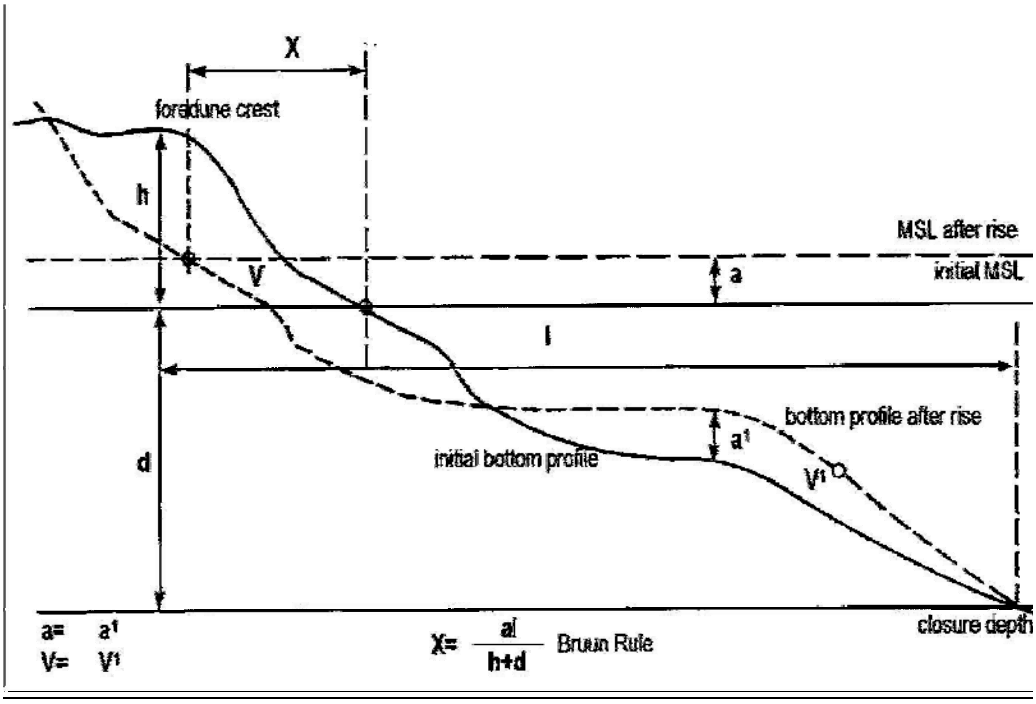


Diagram Showing the Response of the Dune-Beach-Nearshore Profile to Rising Sea Level Where V= Volume, a= Sea Level, X = Erosion Amount, H= height of Foredune (dune crest), D = closure depth, I = distance to closure depth from dune crest (Gibb, 1998).

Qualitative Reconnaissance Surveys

Gibb describes these as a rapid and low costs survey where an “experienced eye” is used to map the spatial distribution of natural coastal hazards. This mapping is supported by a limited amount of research of existing information held by the local authority. The information can be digitised, and then used as a “*sound basis for individual local authorities to design Coastal Hazard Mapping programmes…”*

Areas Sensitive to Coastal Hazards

This system provides further information on the extent of areas which have been identified as being sensitive to coastal hazards. It operates by assessing 13 variables. These are:

i) Elevation of coastal landform

ii) Elevation of maximum storm wave run up

iii) Positive or negative gradient of coastal hinterland

iv) Elevation of maximum tsunami wave run up

v) Coastal lithology including relative erosion potential

vi) Coastal landform including relative hardness

vii) Rate of long term shoreline movement

viii) Maximum amount of short-term fluctuation

ix) Coastal Sensitivity Index (CSI) ranking

x) Width of ASCH

xi) Coastal erosion type

xii) Coastal landslide type

xiii) Coastal flooding type

Determination of the Areas Sensitive to Coastal Hazards (ASCH) is achieved by ranking the first 8 variables into 5 sensitivity classes using a matrix. A specific Coastal Sensitivity Index (CSI) is then derived by numerically integrating the 8 variables and ranking the number into one of 5 general sensitivity classes. The width of ASCH's can be shown visually on vertical maps or photographs of areas. The actual width of these areas is calculated using various criteria for coastal areas in question, and in effect represents an initial assessment with a high degree of professional judgement of the likely extent of areas sensitive to coastal hazards. Following the initial complete assessment of ASCH's, a more detailed assessment of risk within CHZ's is made for high priority sections of coast. A more detailed account of this approach is set out in Gibb (1992 and 1998).

Coastal Hazard Risk Assessment.

CHZ assessments may include one or the combination of a *Coastal Erosion Hazard Zone* (CEHZ), a *Coastal Landslip Hazard Zone* (CLHZ),or a *Coastal Flood Hazard Zone* (CFHZ). Gibb sets out the various factors which are used in these various assessments. These are set out as follows:

Factor X

Is the Rate in metres per year of shore retreat in response to local relative sea-level rise, determined by:

- The standardised Bruun Rule (Bruun 1962; 1983).
- Standardised estimates for potential sea-level rise by 2050 and 2100 A.D. by the New Zealand Climate Committee (NZCC) and the Intergovernmental Panel on Climate Change (IPCC 1996).
- Subtraction of critical local and regional effects from the projections of global sea-level rise by the IPCC.
- Identification of the seaward limit of onshore-offshore beach sediment movement from field evidence (closure depth) below Mean Sea Level (MSL).

The parameters for the Bruun Rule can be determined in the field.

Factor R

Is the Rate in metres per year of long-term (historic) net shoreline advance, retreat or dynamic equilibrium over approximately the last century, for sand and gravel shores and seacliffs, determined from:

- Coastal Resource Maps at 1:5,000 and 1:2,500 Scales incorporating the most recent shoreline position.
- Analysis of reliable Cadastral and sequential Vertical Aerial surveys spanning the last century for areas not covered by the Coastal Resource maps.

Experience is required to separate the long-term (c.100 years) shoreline trend from short-term shoreline fluctuations (10-30 years). Ideally, a minimum of 2 or 3 fluctuation episodes should be spanned.

Factor T

Is the Planning Horizon in years extending from the present up to the years 2050 and 2100 A.D. for which CHZ assessments are made.

Factor S

Is the *Magnitude* in metres of either the *maximum* recorded short-term historic shoreline fluctuation over the last 10-30 years along coasts of unconsolidated sand or gravel, or the *maximum* extent of land that has failed from past or present landslides along unstable seacliffs, determined from:

- Coastal Resource Maps at 1:5,000 and 1:2,500 Scales and Photomaps at 1:5,000 Scale.
- Sequential vertical aerial photography.
- Analysis of survey, anecdotal and historical records.
- Field evidence.

Experience is required to separate the short-term fluctuation from the long-term shoreline trend.

Factor D

Is the *Magnitude* in metres of retreat of the top seaward edge of the erosion scarp cut into sand dunes as a result of slumping to attain a stable slope, determined by:

- The angle of repose of dry loose dune sand determined in the field.
- The height of the dunes above MSL.

Where: $D = \frac{h}{\tan x^{o}} F$

Where	h	=	Height of the main foredune above MSL
	Tan x^{o}	=	Angle of repose (AOR) of dry loose dune sand of approximately 33^{o}
	f	=	Factor of 0.5 to allow for a retreat of a portion of the erosion scarp

The AOR varies from beach to beach and should be determined in the field together with the height of the foredune.

Factor F

Is the *Safety Factor* that is expressed on a scale from 1.0 (0%) to 2.0 (100%), determined by:

- Averaging the sum of the errors for Factors **R**, **X**, **S** and **D**.
- Making adequate provision for a nominal foredune or primary gravel beach ridge at the end of the Planning Horizon.

Factor L

Is the *Horizontal* distance of representative, relatively unmodified natural features such as the beach, shore platform, foredune complex or primary gravel beach ridge, determined by:

- Measurements made in the field and from sequential vertical aerial photographs.
- Provision can be made to accommodate such natural features in the Safety Factor.

Risk Zonation

According to Gibb, the CEHZ is subdivided into *Extreme*, *High* and *Moderate Risk Erosion Zones* and a *Safety Buffer Zone*. The *Extreme Risk Erosion Zone* lies adjacent to the coast and encompasses the area subject to high impact short-term shoreline fluctuations and wind erosion. The *High Risk Erosion Zone* lies adjacent and landward of the *Extreme Risk Erosion Zone* and encompasses the area subject to potential sea and wind erosion, with a high probability of occurring between now and the year 2050 A.D. The *Moderate Risk Erosion Zone* lies adjacent and landward of the *High Risk Erosion Zone* and encompasses the area subject to potential sea and wind erosion, with a high probability of occurring during the period 2050 to 2100 A.D. The *Safety Buffer Zone* lies adjacent and landward of the *Moderate Risk Erosion Zone* and allows for uncertainties in the CHZ assessment.

Reference Shorelines

The CEHZ width is measured landward from the seaward toe of the foredune (duneline) or seacliff (cliffline), top seaward edge of the storm berm on gravel beach ridges, or the line of MHWS where precisely defined by standard survey methods, whichever reference shoreline is the most appropriate.

Using the above factors, Gibb has adopted the following equation for assessments of CEHZs for coastlines with an identified long-term trend of either shoreline retreat or dynamic equilibrium, where:

$$CEHZ = [(X+R)\,T + S + D]\,F$$

For coastlines with an identified long-term trend of shoreline advance, (X + R) T is positive where Factor R absorbs the effects of Factor X. If so, then Gibb considers it highly probable that forecast rising sea-levels, will not cause a reversal from shoreline advance to retreat for the adopted sea-level rise scenario over the planning horizon used for the assessment. For this situation Gibb adopted the following Equation:

$$CEHZ = [S + D]\,F$$

The Bruun Rule cannot be applied to seacliffs, hence factor X is eliminated.

Examples of these assessments are set out in Gibb (1998).

The following equation incorporating the above factors was adopted to assess the extent of a Coastal Landslide Hazard Zone (CLHZ), for the unstable seacliffs and coastal hillslopes of Late Tertiary sandstone-siltstone rocks on the Gisborne District coast and to provide the basis to determine the relative degree of risk (Risk Zonation), where:

$$CLHZ = [(R \times T) + S] F$$

Gibb (1998) has also considered hazards associated with coastal flooding. Flooding hazards tend to be more prominent within enclosed water bodies. In his report, Gibb gives examples of flooding hazard assessments in the Ohiwa and Tauranga Harbours. For Tauranga Harbour, Gibb used the following factors:

i) Planning Horizons

ii) Datum

iii) Mean High Water

iv) Best Estimate Sea-Level

v) Average Maximum SWRU

vi) Root-Sum Square (RSS) Height Error.

A detailed account of these factors and the resulting analysis is set out in Gibb (1998).

As a synthesis of all these approaches, Gibb provides a list of basic information requirements for coastal hazard assessments. He stresses that this information must be of a high standard, and be professionally defensible when challenged. He also places importance on the qualifications and experience of those undertaking the research, pointing out that:

> *"A lack of expertise and commitment always reflects in the final outcome. The empirical equations used for Coastal Hazard Risk assessment are very simple and it is too easy for untrained, inexperienced personnel to make assessments using the wrong basic information.*

From my experience, the greatest traps lie in separating the long-term trend from the short-term shoreline fluctuation, identifying the closure depth, and determining the extent of flooding from the sea. Finally, so much good work can be wasted if the expert cannot provide a compelling well-founded argument or presentation to the decision-makers. The ultimate goal must always be to include Coastal Hazard Zones in Regional and District Plans with appropriate Rules and Policies to control subdivision, use and development along the 15,000km-long New Zealand coast."

The basic information considered necessary by Gibb is:

1. Resource Maps at suitable scales with the capacity for plotted information to be digitised on to GIS with respect to the NZ Map Grid.
2. Geology – lithology, structure, tectonism, beach sediments and sources.
3. Geologic evolution of coastal landform over approximately the last 6,500 years and progradation rates from radiocarbon dated shoreline positions.
4. Coastal and nearshore processes out to about 20-25m water depth.
5. Identify and quantify long-term (100-2,000 years) shoreline trend of either seaward advance, landward retreat, or dynamic equilibrium of reference shoreline not to be confused with short-term fluctuations.
6. Maximum short-term (10-30 year) fluctuations of reference shorelines.
7. Likelihood of a reversal from shoreline advance to retreat and vice versa in response, for example, to sediment budget fluctuations, human interference, or tectonic events.
8. The effects of a projected acceleration in the rate of sea-level rise from an enhanced Greenhouse Effect and likely increase (if any) in storminess.
9. Sensitivity of coastal slopes to landslip and types of landslides.
10. Sensitivity of sand dune complexes to wind erosion.
11. Maximum Storm Wave Runup and Tsunami Runup elevations above MSL from a severe event with an Annual Exceedance Probability of the order of 1-3%.
12. Extent of flooding from the sea and elevations of coastal hinterland at 0.5m intervals in relation to MSL Datum.

13. Extent of river mouth or tidal inlet migration.
14. Dimensions of coastal landforms that provided a natural defence of the coastal hinterland from coastal hazards such as the foredune complex or primary beach ridge.
15. Planning horizon that encompasses the expected occupation life of buildings and services, the occurrence of a severe wave storm or tsunami with an AEP of 1-3%, and the effects of Climate Change from an enhanced Greenhouse Effect.
16. Location and extent of elements at risk from coastal hazards including coastal development and natural, cultural and amenity values.
17. Identifying important local community groups for a managed consultation programme, including hapu and iwi.

1B. T.R. Healy

The method utilised by Healy has been set out in Healy and Dean (in press). It applies specifically to open coast sand systems and therefore any application to other systems (such as estuaries, gravel or mixed sand or low energy coasts) would require expert evaluation as to the relevance of the various parameters. According to Healy, a Coastal Hazard Zone can be specifically defined as:

> *"A sector of coastal terrain that is subject to hazards from the marine environment. Mainly the hazards become manifest as storm wave erosion, storm surge and flooding, or tsunami wave washover."*

Healy and Dean make a distinction between a "Coastal Hazard Zone" and a "setback". The later they describe as a buffer between the beach and any development, which may be for purposes in addition to hazard avoidance. This may include preservation of natural character, cultural matters and amenity values. Healy and Dean generally refer to the two terms synonymously, taking a general definition of a Coastal Hazard Zone to be:

> *"that zone measured as a linear distance landwards from a reference feature, usually taken as the toe of the frontal dune, to a line on the ground which is subject to hazards from the marine environment, and which, on the balance of evidence and in light of scientific knowledge of the moment, it would be prudent to restrict development."*

Healy and Dean describe some of the important cases in New Zealand where the technique of Healy has been applied. The methodology was first evolved in 1976 for the set-back established for the Town and Country Planning Appeal Board case at Piripai, Bay of Plenty, where the board imposed a set-back of 60 metres. Healy and Dean also refer to the Matarangi and Papamoa cases, both of which have been referred to above in relation to the techniques of Gibb.

The general formula utilised by Healy can be summarised as:

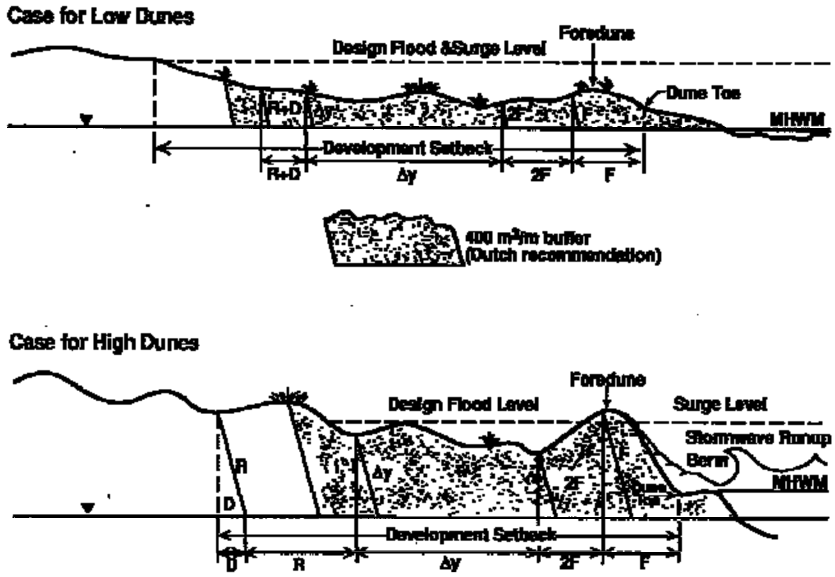
$$CHZ = R + 2F_{(max)} + \Delta y + D$$

Where:

CHZ	=	a linear distance measured in land from a reference point (which Healy and Dean prefer to be the toe of the frontal dune)
R	=	long term shoreline erosion or accretion rate
$F_{(max)}$	=	is the decadal term duneline fluctuation- the maximum observed cyclical fluctuation of extreme storm cut
Δy	=	dune line retreat due to sea level rise
D	=	dune line stability factor

A two dimensional representation of these factors is imposed on two hypothetical cross sections in Figure A4. Note that it is depicted only for sandy coastlines with dunes. These factors are derived in a similar way to the method set out by Gibb. Factor R (long term duneline trend measured in m/100 years) can be obtained from historical MHWM surveys dating from earlier centuries, or from repetitive dune/beach surveys where they exist, or vertical air photos.

Figure B4.



Two Dimensional Representation of Hazard Zone Determination (Healy and Dean, *in press*)

$F_{(max)}$ is a measure of the maximum duneline "cut and fill" from rare storm events representing short to medium term trends which are superimposed on the long term trends. These relate to either episodic events or decadal trends. Healy reports a surveyed $F_{(max)}$ for the Bay of Plenty as a 20m duneline retreat, or about 120m^3 per metre of beach cut after a major storm (Healy 1978,a,b *reported in* Healy and Dean in press).

Healy and Dean note that a safety factor may be applied to $F_{(max)}$ because little data is often available on the magnitude of episodic storm cuts, or on the long term trends. Based on statistical evidence relating known events to a 1% AEP (1 in 100 year) event, Healy and Dean recommend a safety factor of 2 be applied.

The effect of sea-level rise (Δy) is explicitly considered in the Healy formula. Healy and Dean (in press) make a clear case for including estimations of historical and accelerated sea level rise in a hazard formula, responding to doubts that such predictions are scientifically credible. They conclude that:

"There is substantial evidence of historical sea level rise on a world scale of approximately 12cm per century (Barnett 1983; Barth and Titus 1984;

Pirazzoli; Bruun 1986, 1987, 1990; Stewart et. al. 1990; Gornitz 1993), but the projected rate of future sea level rise is an issue (Warwick 1993 a,b; Aubrey and Emery 1993).

Healy and Dean point out that the relative sea level change in any single location is only specific to that site. Local effects, most importantly tectonic processes, need to be explicitly considered. When it is known that a given sector of coastal is subject to measurable uplift or down sinking, then Healy and Dean recommend that the assessment of the projected local relative sea level change (Δs) should appropriately reflect these additional effects, i.e

$$\Delta s = \Delta S_L \pm \Delta T \pm \Delta G$$

where Δs is the long term (100 year) projected sea level change rate, ΔT is the 100 year vertical tectonic movement of the shoreline and ΔG is any discernible change in the ocean geodynamic surface. Healy and Dean warn of possible “double dipping” when using both a sea level rise projection (Δs) in conjunction with a long term erosion rate (R) . This is since the existing beach profiles are presumably already adjusted to the local historical rate of sea level rise, which is implicit in the determination of R. Accordingly, they recommend that this effect be subtracted from the future projected local sea-level rise, as was set out by Gibb and Auburn (1986) as being achieved by:

$$\Delta s' = \Delta s - \Delta s_h$$

where $\Delta s'$ is the “net local relative sea level rise effect”, Δs is the local relative sea level change projection, and Δs_h is the historical local relative sea level change of a period of between 50 and 100 years.

In terms of assessing the response of the coastline to a change in sea-level, Healy and Dean rely on the same two dimensional model developed by Bruun as was reported by Gibb (1998). However they also report on the method of Weggel (1979) which included an explicit consideration of dune height and the modified Bruun rule developed by Dubois (1977). These are set out on page 10 of Healy and Dean (in press).

One of the most frequently cited problems with the Bruun rule and its derivatives is the estimation of closure depth. Healy and Dean refer to the work of Hallermeier (1981), who has developed statistically based inner and outer closure depths which relate wave climate and grain size. The inner limit (HIL) represents the limit of day to day exchange of sand from the surf zone to the beach and the outer limit (HOL) conceptually defines the maximum offshore extent of storm wave induced sediment transport.

CUR (1987) (*reported in* Healy and Dean (in press)) note that for practical purposes the inner limit may be taken as 1.75 times $H_{s0.137}$ and that the outer limit is about twice that or 3.5 $H_{s0.137}$ where the $H_{s0.137}$ is the maximum nearshore significant wave height occurring for 12 hours per year. Examples of inner and outer Hellermeier limits are provided on pages 11-12 of Healy and Dean (in press).

The dune topographic stability factor (D), makes allowance for the natural angle of repose of dry dune sand which is about 30°. Any severe dune cut back may well pose a hazard to development well back from the dune line due to this angle. Thus for every 1m elevation of dune, one needs approximately 2m linear distance to allow the dune sand to rest at its natural angle of repose. The dune stability factor is given by Healy and Dean (in press) as:

$$D = E/\tan\propto$$

where $\tan\propto$ is the natural angle of repose of the dune sand, and E is the elevation of the dunes, above datum.

In addition to the application of the above formulae, Healy and Dean consider it necessary to test the resulting CHZ against 4 parameters, to determine if the zone is appropriate for the potential hazards for the particular geomorphology of the site. As the overall method of Healy is related to sandy beach environments (and their dune features), some of these factors are related to dune volumes and would need to be modified or not considered for other locations. The factors set out in Healy and Dean are:

1. Episodic Storm Cut and Sand Reservoir Considerations.

   This factor attempts to determine how much loss can be expected in a (probably unrecorded) worst case or 1 in 100 year erosion event. As such events are virtually unrecorded anywhere, Healy and Dean recommend using the standard adopted by Dutch engineers (van de Graff 1986, 1994 CUR, 1989 *reported in* Healy and Dean (in press) and to retain a sand reservoir of $400m^3 .m^{-1}$ within the CHZ above a mean sea level datum after the worst known storm cut. For such conditions a storm surge and run-up of approximately 5m is assumed. To convert a storm profile cut into a linear distance, it is necessary to take into account the height of the dune field (E). Therefore the following test applies:

$$CHZ > (\Delta_{V(max)} + 400)/E$$

2. Storm Surge Wave Washover and Flooding

This factor acknowledges that if the general dune (or coastal) topography within the initially specified CHZ is lower than the design surge flood level, the CHZ must be extended landwards until the terrain is sufficiently high. The parameters to determine these are the same as set out above in relation to the Gibb method, and the exact formulae derive from Frisby and Goldberg (1981) and are reproduced on pages 14-15 of Healy and Dean (in press). Healy and Dean note that for the Bay of Plenty coast a spring tide along this coast is 0.8m, barometric set-up for a severe storm is 0.35m, wind set-up for a 40knot wind over a 25km wide inner shelf is 0.23m, wave set-up for a H_b= 11.5m is 1.39m for the 10% highest waves and wave run-up depends on slope. Total design wave run-up therefore ranges between 4-5m, which accords closely with the flotsam line after cyclone Bola in March 1988.

3. Possible Tsunami Hazard

Although the likelihood of having a sufficient data base to accurately portray tsunami induced run-up is low, they are of relevance to the New Zealand coast due to its tectonic nature and its Pacific location. Where some information does exist, the elevation of the frontal dune or coastal feature (E_f) should be higher than the known tsunami run-up level, given by:

$$E_f > h_{ts}$$

Where h_{ts} is the tsunami runup inundation level. Details on calculating this variable are given in Healy and Dean (in press).

2. COMBINED QUALITATIVE-QUANTITATIVE

2A. (R.M. Kirk, M. Single, P. Kench (ed)

The approach of Kirk and Single has been summarised in a report by Kirk (1999). Unlike some approaches used to identify coastal hazards, which reply on equations and process-morphology relationships to simulate and predict behaviour, the approach adopted by Kirk and Single cannot be so easily prescribed. The approach embraces a holistic philosophy of coastal management which is intricately linked to the underlying principles of the Resource Management Act. This does not imply that process-response relationships have no place in the approach, rather such equations are used only where appropriate and are only one component of an overall hazard assessment. Such an overarching approach has been adopted by this strategy document, and is illustrated in Figure 9.

The Kirk and Single approach has evolved over the past 25 years as a result of experience addressing a variety of site specific problems around the New Zealand coast. The approach has also evolved in response to changes in legislation, in particular changes in the Town and Country Planning Act up to 1977, and the more recent introduction of the Resource Management Act 1991. The incorporation in legislation of matters such as the preservation of the natural character of the coastal environment has encouraged inventive management solutions to mitigate hazards by harnessing existing coastal processes. Furthermore, Kirk notes that the approach has evolved through a realisation that simple models and equations that seek to reduce complex coastal behaviour to simple relationships, which have been applied and derived for specific coastal settings, are not applicable or transferable to all coastal types (Kirk, 1994). This has meant that the approach has had to adopt different analytical tools that are appropriate to the coastal type under investigation, and a range of different strategies have developed to manage hazards at different coastal sites. Kirk (1999, 24) concludes that *“this is a particular strength of the approach in that it avoids treating different coastal sites as homogenous with respect to the process regime, long term coastal behaviour and human use but instead reflects the heterogeneous character of the New Zealand coast, its landform types, processes, morphodynamics and human uses”.*

The approach is underlain by some common principles. According to Kirk (1999) these are:

- That there are ‘internationally accepted principles of coastal processes’ that operate in a diversity of coastal settings (e.g beach, dune, estuary, inlet, spit and cliff). Over the past three decades there has been a wealth of fundamental research on physical processes controlling coastal behaviour. For a number of sites this knowledge has evolved to a point where fundamental principles of beach behaviour are established. For example, short-term fluctuations in beach volume in response to storm and swell regimes is a generally recognised process. Recent research has also shown that beach volumes can fluctuate over much longer time scales (decades) in response to shifts in major controlling processes (wave climate, frequency of storms, ENSO). Furthermore, research has shown that beach systems can exchange material alongshore, offshore and landward. Increasingly scientists and managers have become aware that sediment budgets and maintenance of sediment flows are essential in order to ensure beach systems are maintained.

- The above key principles are portable between coastal settings having similar morphologies but different tectonic, structural, sedimentation and marine processes regimes. Equally it is understood that principles of physical processes apply to a wide range of cultural, social, economic and regulatory regimes on the coast. These are important considerations for 3 reasons:

(i) The New Zealand coast is highly variable from place to place: in physical, ecological and land use terms. It means that results from investigations on one part of the coast are generally not transferable to different coastal landform types (e.g results from sand beaches are not applicable to gravel beaches, though attempts to do this have occurred). In this instance it would be best to apply generally accepted principles of gravel beach behaviour to gravel coasts when evaluating hazards and designing mitigation or avoidance strategies.

(ii) While knowledge of the New Zealand coast is rapidly increasing, the short history of ‘formal coastal management’ means that there is generally poor information on coastal processes (e.g the height and period of waves occurring in storms and extreme water levels) and coastal dynamics (e.g the precise history of coastal change) at most places in New Zealand.

(iii) Coastal processes and their interactions with land-use are complex phenomena that require skilled interpretation based in international research in similar coastal settings, especially in situations where key data on processes is absent or severely limited.

In order to account for this variation, Kirk advocates the use of different methods and tools in assessing coastal hazards at different sites. While the approach may adopt some simple equations (e.g for runup) such equations comprise a small part of the overall assessment.

- The adoption of 'internationally accepted best practise to managing coastal problems'. The approach assumes that management solutions, which have been developed, successfully tested and evaluated in scientific and management literature, and are equally as portable as physical principles of coastal systems. This is considered important in New Zealand where limited knowledge and experience means that the lessons of comparative experience both within New Zealand and internationally are very valuable.

- The explicit recognition that coastal hazard 'risk' varies not only as a result of different physical conditions and geomorphic processes along the coast but also as a result of demographic, economic and social factors and land use activity patterns. In this system, Kirk (1999,3) refers to 'risk' as being defined by Kirk and Single as *"the product of a probability (e.g of storm waves having some stated height) and a consequence (e.g the dollar value of the assets and infrastructure and/or the conservation and amenity values of coastal features.)"*

In expanding on this issue, Kirk expresses a concern that erosion and coastal hazards are often seen as being an entirely natural phenomenon. This approach *"does not embrace the fact that erosion is as often human generated through our actions on the coast, as it is natural, or that it is frequently the outcome of a history of some combination of natural processes and our uses of the environment"*(Kirk, 1999, 38). Therefore, the approach resists treating coastal land as being effectively vacant, but takes explicit account of the human dimensions of the coast.

Kirk considers that effective management of existing hazardous areas implies that not only are existing hazards mitigated, but future hazards are also avoided. For example, actively managing the dune environment as a buffer against contemporary erosion and inundation hazards must also contribute to mitigation or avoidance of hazards in the future. Failing to take this approach would *"merely delay the impact of hazards landward of the setback point."*(Kirk, 1999, 40). Furthermore, ongoing monitoring of the coast before and after hazards are assessed and management strategies are implemented allows these strategies to be modified as a better understanding of coastal processes and responses becomes available.

- Flexibility so that particular physical and human characteristics of each coastal environment and the specific issues drive the hazard assessment (methods and techniques used) and use of specific criteria to evaluate hazards. This is based on:

  (i) recognition that coastal hazards result from the interaction of physical systems and human-use systems. In this respect the approach is considered by Kirk (1999) to be unique in that it evaluates the human dimension of the perceived/actual hazard.

  (ii) recognition that a particular coastal landform type (e.g beach systems) may be quite similar in process, but quite dissimilar in use. These differences become an integral part of the assessment of how hazards are determined and how the hazard is exacerbated, mitigated, remedied or avoided.

- Rendering clear and ration advice based on an assessment of coastal processes and human-use interaction in such a way that decisions on actions to mitigate, remedy or avoid hazards are clear, transparent, logical and defensible.

- Adopting an inter-disciplinary approach which recognises the desirability of partnership involvement between different sections of the community. Kirk (1999,4) states that in the Kirk-Single approach *"It is frankly recognised that no one discipline is the home of coastal management. Rather, its essence is that it is an interdisciplinary undertaking often requiring the professional input of skilled planners, lawyers, engineers, surveyors, biologists, ecologists and social scientists. Of equal and growing importance is active participation at all levels by iwi and by the* *community living and working on the coast."*

- The approach advocates the pro-active management of hazardous areas in order to conserve and protect the natural character of the coast and its processes while promoting sustainable use of its resources. An example is the conservation of dune sand resources to conserve and increase the buffers against erosion and inundation. This approach attempts to assess the value and resource of the areas defined as hazardous, which can be used to further mitigate against coastal hazards (e.g through repair of dune blow-outs, planting and access control).
- Hazard judgements in this approach are given without reference to a time frame (such as 50 or 100 years). An earlier discussion has highlighted the issues associated with this matter.

The steps set out in Figure 9 are those recommended by Kirk (1999). The identification of parameters of the coastal sites can be divided into physical and human dimensions. Each of these however need to be fully assessed and understood before the dimension of the coastal hazard can be ascertained.

Information required on the physical characteristics of the coast includes:

- Coastal landform type under investigation, and history of its development;
- Morphology of the coastal environment- types of geomorphic units;
- tidal regime- range and frequency
- current regime- significance, speed and direction
- wave climate- mean, significant and maximum wave heights, and direction
- wind regime- mean and maximum and direction
- estuarine hydrology
- water levels and survey marks
- secular sea level- any local information or records over various time scales

- projections for future sea level rise, and confidence in those predictions
- storm related water levels resulting from various Storm Wave Runup factors
- storms- any information on their character, frequency, direction, recurrence intervals and magnitude
- tsunami
- morphodynamics- evidence of recent coastal changes (storm deposits, stranded ridges)- is the coast accreting, eroding or fluctuating in position through time?

Information required on the human-use characteristics of the coast includes:

- type and proximity of existing development to the coast- in what geomorphic units has development occurred?
- type and proximity of planned future development of the coast
- modification of the natural character of the coastline associated with individual developments (e.g dune recontouring or removal)
- is there is history of sediment extraction at the site, from the adjacent seabed or from functionally related parts of the coast (e.g up drift sites)
- are there any activities or developments that impact on the coast, e.g storm water drains.
- what activities do operative district and regional plans provide for at the site?
- Are there future plans to allow or change activities permissible at the site?
- what recreational uses does the coast have?
- what economic value can be placed on parts of the coastline, which may be threatened by hazards?
- does the coast have any significant cultural values? If so where, and what is the nature of those values?
- are there any demands on the physical coastal resources from off-site or down stream uses (e.g nearshore sand extraction)
- are there any structures that have previously been built at the site in order to provide protection for development infrastructure? If so, what is the history of such works and are they having any consequential effects on coastal processes?

- have any other practises been undertaken in order to protect the coast (e.g beach nourishment)?

<u>Identification of the Dimension of the Hazard</u>

Kirk (1987) notes that typical manifestations of hazards include:

- mass movement of coastal cliffs
- nuisance or damage from sand blown or eroding dunes
- loss of buffer function against erosion and/or inundation by dissipation or 'landscaping' of dunes
- encroachment of the sea onto properties leading to loss of support and collapse of dunes, cliffs and structures
- inundation by seawater from runup of broken waves or tsunami
- inundation by tailwater effects of high storm sea levels or freshwater or estuarine damage
- scour around buildings from runup, damage by wave impacts on properties or structures

While the type or most obvious hazard affecting a coastal site may be known prior to a thorough analysis of hazards (e.g erosion), rarely are the full spectrum of hazards, the extent of the hazards or the underlying mechanisms promoting the hazard (human or physical) clearly understood.

Once an assessment of the physical and human components of the coastal site has been made, a closer examination of physical processes and human activities is undertaken in order to delineate the actual hazards, the extent of hazards and factors promoting or exacerbating the hazard.

<u>Identification of the Natural Processes and Dynamism of the Coastal Site.</u>

This stage characterises the dynamism of the coast with respect to temporal and spatial processes and morphological change. Typically this would include an assessment of:-

1. Where erosion or accretion is prevalent at the coast and the rate and difference in erosion/accretion along the coast. Kirk (1999) pointed out that changes in the shoreline occur in response to a variety of processes over a range of time scales. Short term responses caused by changing wave regimes involve large quantities of sand and result in wide ranging displacements of the water line. Over many surveys it is possible to define the envelope or 'sweep zone' that encompasses the range of short term beach positions. Thus, perceived short term erosion events that lie within the sweep zone do not represent long term erosion of the beach. In the longer term, changes in sediment supply to the coast or sea level can cause lateral displacement of the entire sweep zone. Landward movement of the sweep zone is indicative of long term erosion at the coast, whereas seaward movement is indicative of accretion.

2. Inundation levels along the coast. This requires an assessment of land elevation with respect to wave runup, storm surge, wave setup and tsunami levels.

3. The envelope within which highly dynamic coastal features move (spits inlets, channels, dunes and beaches).

4. rates and areas subject to sedimentation (aeolian, littoral or estuarine).

Techniques to assist in determining these factors are set out in detail in Kirk, 1999, and are not described here. The typical outputs expected by Kirk from this process are:

- identification of rate/magnitude and extent of natural processes:
  - erosion/accretion or sedimentation
  - wave runup
  - storm surge
  - inundation

- delineation of envelope of change of dynamic coastal features (spit movement, beach change)
- identification of progressive changes in coastal systems (dune development, coastal accretion).

Assessment of Human Activities Exacerbating Hazards

The effects of human activities at the coastal site are assessed to determine:

1. Whether human modification and/or activities have altered processes, which in turn have altered the rate or scale of coastal change and processes. In particular, have actions exacerbated erosion or made coastal land more susceptible to inundation. This may require parallel analyses of coastal change. For example, aerial photograph interpretation of human settlement change and the insertion of structures or new development may coincide with an increased rate of erosion. It is also necessary to examine human influences at sites spatially separated from the coastal site of interest as activities may have alongshore consequences for the assessment site. While some hazard assessments focus on the location of buildings relative to the coast, Kirk (1999) recommends that it is important to consider a much wider sweep of the uses of coastal land that are attendant on the locations of buildings and the infrastructure that services them (e.g roads, storm water drainage, sewage, electricity, telephone and water systems).

2. Whether structures inserted at the coast are accelerating coastal change and whether physical structures pose a hazard to the coastal site. In this respect reference should be made to the guidance given in the Coastal Erosion Management Manual. The manual provides guidance on the likely effects of various types of structures, and their interaction with physical coastal processes.

The typical outputs expected by Kirk from this process would be:

- Identification of a range of management options to avoid, remedy or mitigate hazards at the coastal site

- Design and implementation of an appropriate monitoring programme

Examples Where the Kirk-Single Approach has Been Employed

The approach outlined above has been applied in numerous assessments of hazards throughout New Zealand. Two of the most significant examples of this approach are at Washdyke Lagoon, South Canterbury, and South Brighton Spit, Christchurch. These are summarised below, and a detailed discussion of these cases is set out in Kirk (1999, 25-36, and Appendix 3).

Washdyke Lagoon

This lagoon is located on the northern margin of Timaru. Kirk (1983) states that Washdyke beach experiences one of the most sustained and severe erosion problems in New Zealand when measured either as an annual rate of retreat (between 4 and 12 metres per annum) or by the value of assets at risk ($100m in 1998 dollars), or a combination of both. Professor Kirk was engaged by the Timaru District Council to determine the magnitude and scale of coastal hazards in order to amend the District Planning Scheme so to avoid the generation of further unwanted hazards to development.

The hazard assessment evaluated repetitive beach profiles which identified significant horizontal and vertical erosion of the gravel barrier/beach, suggesting eventual breaching and loss of the barrier and lagoon system. Using historical and document evidence of the breaching and loss of the similar Waimataitai gravel barrier and lagoon (updrift of Washdyke) earlier this century, estimates of shoreline storm surge and measured beach erosion were combined to predict future barrier breaching, loss of lagoon and re-positioning of the shoreline to the year 2030 (Figure A5). This analysis also identified areas subject to flooding and erosion hazards.

The management strategy proposed was based on zoning activities within the hazard areas and on promoting the hazardous zone as a sand conservation area. A trial beach nourishment programme was also undertaken following the assessment over a 6 year period. Considerable reductions in erosion and overtopping rates were achieved (Kirk and Weaver (1982) and Kirk (1992) reported in Kirk, 1999). Continuous monitoring of the site was put in place in order to ensure that the hazard management response could be review, and if appropriate relaxed, if monitoring demonstrated that the extent of the hazard was reduced.

South Brighton Spit, Chrischurch.

South Brighton Spit encloses the Avon-Heathcote estuary and forms part of the 16 kilometres of sandy beaches and dunes along the urban margins of the Christchurch metropolitan area. Following severe erosion events in the late 1970's the Christchurch City Council commissioned a study by Kirk of the coastal processes and stability of beaches on the spit. In 1979 Kirk produced an assessment of coastal hazards in the area, including the entire urban foreshore. Particular attention was given to the South Brighton Spit area because of its highly changeable nature.

Kirk investigated the physical factors responsible for changes in length of the spit by as much as 500m since 1849. This led to the development of a management strategy (including planning options) to mitigate erosion hazards at the site. In contrast to Washdyke (a gravel barrier), the South Brighton coastal site is comprised of sandy beaches terminating in a dynamic spit tip. Therefore, some of the different factors needing assessment included examination of the spit and dune dynamics, tidal hydraulics and estuarine hydrology. Furthermore, the spit had a long history of human settlement.

The approach taken by Kirk for the spit was that on a spit tip, which sometimes advance and at other times retreat, key aspects of hazards are that erosion is certain, while its timing, magnitude and location are not at all predictable. Options to mitigate these hazards were designed in conjunction with planners and City Council officers. Importantly, the coastal site contained substantial coastal development, which influenced the mitigation options. In particular, in the most hazardous sites planning restrictions were implemented. Furthermore, recognition was given to the fact that the principle protection for the area derived from a narrow, low foredune system added to the seaward side of the spit since 1955 (Figure A6). Protection and enhancement of the physical integrity of this dune line and avoiding a concentration of houses along it were seen as key outcomes of the assessment.

2B Tonkin and Taylor Limited

The report of Tonkin and Taylor Limited sets out two distinct methodologies for “beach” shoreline and for cliff areas. The beach shoreline methodology set out by Tonkin and Taylor Limited is based on *“developing an understanding of the physical system. This information is utilised to create hazard zones based on the observed and predicted physical changes. A final ‘pragmatic’ review is then used to create and locate the final hazard zone based on developed levels of confidence and ‘on the ground’ development.”*

The methodology set out by Tonkin and Taylor Limited relies on a 7 step process. Those are:

i) Collect, evaluate and analyse data
ii) Visit site
iii) Quantify impacts
iv) Identify causes of change
v) Develop coastal process “system” model
vi) Assess impact of sea level rise
vii) Develop hazard zone

The first 5 steps involve the development of a clear understanding of the existing system as background information. Step six is a predictive process in which future shoreline changes due to sea-level rise are assessed. Step seven presents the hazard zone thus far developed, discusses the relevant practical considerations of delineating the hazard zone and concludes with considerations required to produce an overall consistency check on the results.

Step 1 is common to all of the hazard assessment methods. Tonkin and Taylor Limited set out a specific list of information sources which can be utilised to gain an understanding of the physical system. These are:

- cadastral surveys (recent and historic)
- charts and maps
- aerial photographs (recent and historic)
- sand extraction data

- survey data
- historic reports (including subdivision consent reports)
- physical data (physiography, lithology, beach sediment properties, wind, wave and tidal current data)
- climate information
- hazard register information
- anecdotal information
- information on adjacent or similar sites.

Tonkin and Taylor Limited point out that an assessment of the quality and quantity of the information needs to be made by a suitably qualified person and that it is important to note that data quality is as important as the length of the record. In that respect, Tonkin and Taylor Limited consider that data, even from combined long term records over a period greater than 50 years, is considered more useful than short term changes. However, short term changes are more easily evaluated (using modelling) or measured, than long term trends. Better quality information on shoreline changes at both long and short time scales leads to a higher level of confidence in the resulting hazard zone assessment.

Where such information is unavailable, Tonkin and Taylor Limited recommend several alternative techniques which can be used, including:

- monitoring until a sufficient dataset is created (usually impractical due to the time needed to create a useful dataset)
- use numerical models to simulate expected shoreline changes and/or development
- utilise hazard zones from adjacent and/or similar areas (this should be done with extreme caution and reference to the particular geomorphic conditions of the site)
- zone based on geomorphological controls only (e.g landward limit of dune system)

Tonkin and Taylor Limited point out that while most of these options can be used to develop a meaningful hazard assessment, it must be accepted that with less data, or lower quality data, a more conservative assessment is usual.

Figure B5. Predicted Changes in Shoreline Position at Washdyke Lagoon, Timaru (Kirk, 1999)

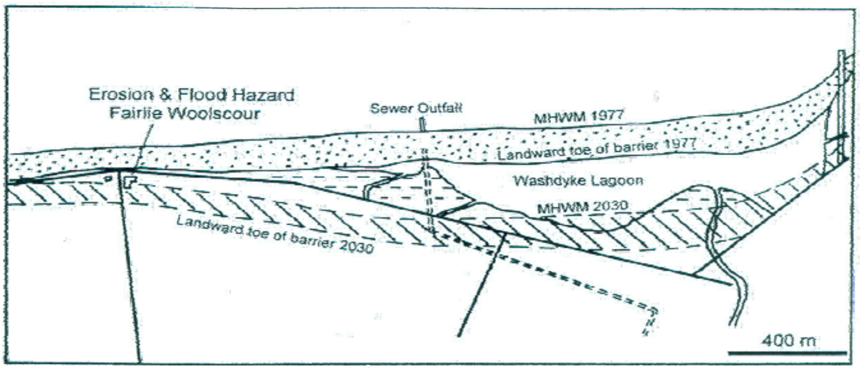
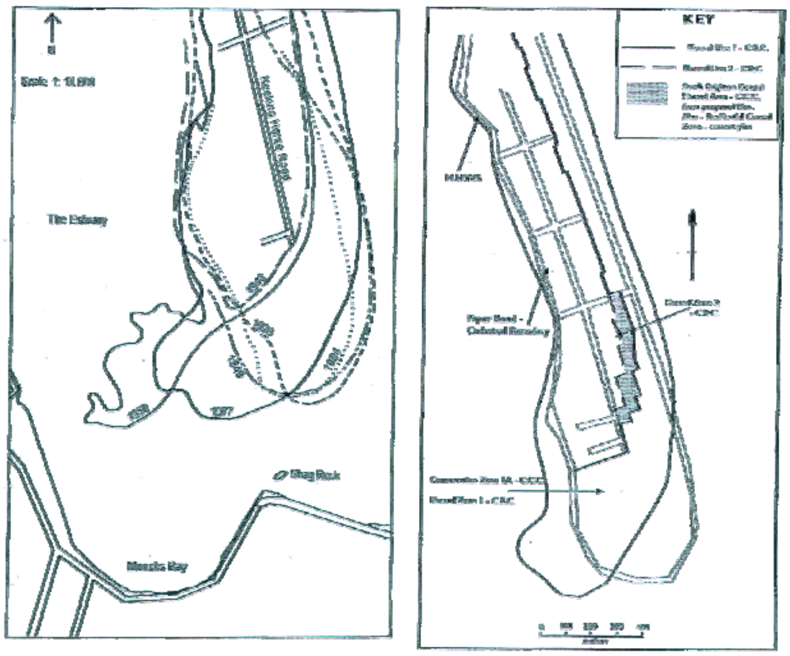


Figure B6

Historical Changes in Spit Configuration 1849-1977 and Resulting Hazard Zones, South Brighton Spit, Christchurch (Kirk 1999(



Quantification of impacts involves taking the historical information and quantifying changes. The desired outcomes of this stage are:

1. Quantification of the effect of major storms on shoreline erosion both with respect to shoreline retreat and upper beach/dune volume loss (storm demand). According to Tonkin and Taylor Limited this is largely achieved through analysis of beach cross-sections possibly supplemented with numerical models. The authors warn that the assessment of storm demand should be approached with caution, and is dependent on the interval between surveys. This is since the

maximum erosion is often at the peak of the storm with beach rebuilding occurring even as the storm subsides. Therefore survey dates and the time of the storm should be known and an assessment made on the suitability of the information.

2. Storm demand should be estimated or assessed for 1:50 or 1:100 year (2% or 1% AEP) events. If there is no significant storm event within the period of observation, Tonkin and Taylor Limited recommend that appropriate numerical models can be used to assist in developing estimates of storm cut based on particular storm characteristics. Alternatively, the authors suggest that a factor of safety can be applied to historical estimates.
3. Quantification of historical shoreline trends. As with other techniques, this is achieved through analysis of aerial photographs, cadastral surveys and map interpretation, and (where possible) beach cross section analysis.
4. Quantification of impacts from catchment development and other historical ‘structural’ changes to the system, for example, impacts of stormwater outfalls; adjacent coastal structures or other forms of coastal development; access ways; removal of coastal vegetation; dune modification, placement of fill and re-contouring etc.
5. Delineating areas specifically affected by short and long term trends or effects (i.e stream mouth or spit tip migration, coastal adjustments due to structures etc). This can be achieved through aerial photographs, cadastral and map assessments, site visits and numerical modelling where appropriate. New and innovative methods of monitoring and data assessment should also be considered such as sledge surveys for beach cross sections, digital terrain models and remote video camera monitoring.

Tonkin and Taylor Limited point out that when collating this information, a common cause of confusion and subsequent error is the datum used in various data sets. Resolving the differences in datums and establishing a common datum is essential prior to analysis. The authors recommend using the local land based survey datum, typically around Mean Sea Level, and also recommend caution when assessing the potential error that might be expected from scaling aerial photographs, and various interpretations of survey boundaries. The authors refer to new methods of digital photogrammetric correction and digital terrain models as several ways in which error can be minimised.

The identification of the cause of change looks at various causes for any trends or instances of erosion that are evident, including:

- climatic and weather related events (ENSO, Storm impacts)
- headland erosion
- stormwater/stream/river flow
- changes in sediment supply
- sediment removal
- coastal structures

The development of a coastal process "system" model involves utilising the information collected to develop a model of how the beach is responding to change over time. The model should be capable of being used to explain and quantify historic long term and short term changes to the shoreline, as well as cyclical trends (SOI etc). Important questions that the model should be able to answer include:

i) Are shoreline changes a result of modification to the system (natural and artificial)?

ii) Are changes temporary or permanent?

iii) Are changes likely to continue?

<u>Assessing the impact of sea-level rise.</u>

The Tonkin and Taylor Limited methodology is similar to both the Gibb and Healy techniques in that it assesses the historical rate of rise, and also makes an informed judgement on the most appropriate parameters to use when investigating future (and possibly accelerated) sea level rise.

Tonkin and Taylor Limited refer to the research of Hannah (1990) and its conclusions of a historical sea level rise in New Zealand of around 1.1 to 1.7mm/yr. They also note however, that recent research by Bell and Goring(1997) for the Motiriki sea level recorder at Mt Maunganui, show a slight decrease in sea level from 1973 to 1994. These changes are likely due to seasonal and ENSO climatic effects, but point to the uncertainty in trends when general trends are applied to specific locations.

Accelerated sea level rise effects, and its associated issues are described in detail in Section 5. Tonkin and Taylor Limited consider that the estimates of global accelerated sea level rise produced by the IPCC is the best information currently available.

As with Gibb and Healy, Tonkin and Taylor Limited recommend the use of the Bruun rule to determine the two dimensional effects of a rise in sea level. As with Healy, they also recommend that adjustment to the derived rise should be made to take account of local uplift or down lift effects, and also agree that it is credible to extract the historical rate from estimates of accelerated rise to avoid “double dipping”. Tonkin and Taylor Limited also refer to the work of Hallermeier for determining the closure depth in the Bruun rule, however they warn that the wave climate information for New Zealand is so sparse that assumptions are often made when using these formulae. The development of a Wave Climate Strategy by the ARC should assist in resolving this problem. The report notes that in some cases which are frequent in Auckland (such as the perched beaches of the North Shore, or the wide flat foreshore of the Waitemata and Manukau Harbours) the application of the Hallermeier formula may reflect the inner limits, rather than the outer, deeper water limits.

The development of a coastal hazard zone, using the Tonkin and Taylor Limited approach is based on summing the horizontal changes to the shoreline due to:

- Short-term fluctuations (storm demands)
- Long term trends
- Accelerated sea level rise impacts
- Factors of safety. These can be applied at each stage depending on the level of confidence in the information derived from the earlier parts of the study and the degree of risk.

A number of zones can be developed from the resulting data that relate to the level of hazard:

- Extreme Risk Hazard Zone: the area subject to observed or predicted storm erosion impacts from a 1 to 2% AEP storm event and the cyclical shoreline movements.
- High Risk Hazard Zone:, includes the area subject to erosion due to extrapolating appropriate historic erosive trends and sea

level rise impacts for a 50 year planning horizon.

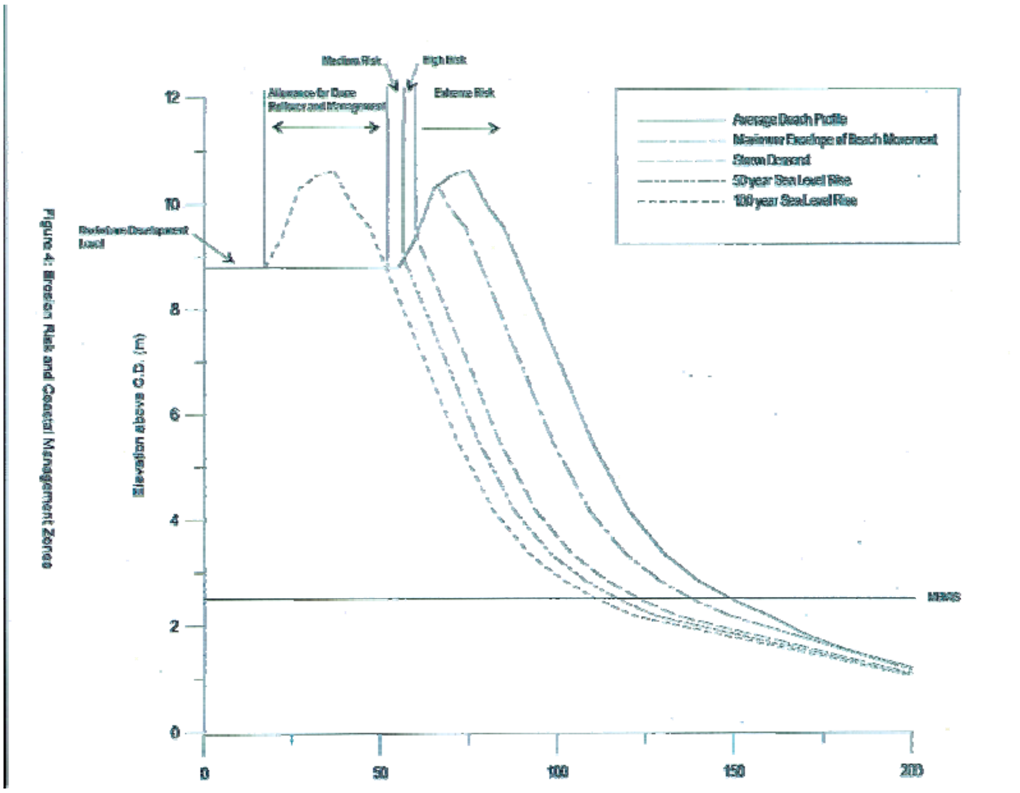
- Maximum Risk Hazard Zone: made up of the lesser distance based on either the area subject to erosion due to extrapolating appropriate historic erosive trends and sea level rise impacts for a 100 year planning horizon, or the maximum extent of the geomorphic unit where alternative lithological conditions occur.

Further hazard zones can be established due to site specific needs. A generalised schematic of these zones is illustrated in Figure B7.

The actual zones are developed in the Tonkin and Taylor Limited method by working from each beach profile location along the sandy shore where information is available. The lines are then interpolated between profiles, taking into account all knowledge gained during the investigation including aspects such as the existing topography, physical features, processes and human modification.

The report recommends that short-term fluctuations, such as storm cut should be checked both with respect to rates of horizontal retreat and associated volume loss. If the rate of horizontal retreat provides a greater volume loss that predicted, the extent of retreat should be modified to more closely match the storm volume loss estimates.

Figure B7.



Erosion Risk and Coastal Management Zones (Tonkin and Taylor Limited, 1998

Locating the Hazard Zone on the Ground

Tonkin and Taylor Limited recommend that the appropriate level to locate the start of the hazard zone is the mid point between MHWS and the toe of the dune if there is no evidence of a long term trend of erosion. . If data does indicate a long term trend of erosion, then the report recommends using the toe of the dune (if present). The final zone widths should include the horizontal distance at the reference level, and should take into account the actual, or representative slope of the beach and backshore from the reference level to the landward ground elevation. The report recommends that provision of additional space for other potential effects such as dune roll-over should also be considered in providing an additional buffer area.

The report recommends that hazard zone widths should be rounded up to the nearest whole number to avoid false precision. Also, Tonkin and Taylor Limited state that any predicted longshore variation in hazard zone widths along the shoreline should be critically reviewed and these variations should be able to be justified.

In comparatively assessing its own method, Tonkin and Taylor Limited states that its technique is strongly focused on:

- clearly identifying and delineating causes of erosion to minimise the erroneous spatial and temporal extrapolation of local anomolies to beach wide trends. The report states that this requires a holistic approach to data interpretation.
- Utilising field data, modern analysis techniques and numerical models to provide the best information and methods available.
- Providing a logical method of locating the starting position of the hazard zones in the field.

The report concludes that by considering these factors, uncertainty is better identified, and therefore appropriate factors of safety can be more accurately evaluated.

<u>Coastal Cliffs</u>

The Tonkin and Taylor Limited methodology explicitly considers hazard definition for coastal cliffs, and assesses the distinct approach required to determine hazardous areas in these locations. The report sets out the following methodology:

i) define the physical factors potentially affecting cliff stability
ii) determine the mechanisms of failure
iii) calibrate with historical observations
iv) establish a model for cliff retreat
v) assess the effects of any future change

vi) modify the cliff stability model, as required

vii) predict cliff slope performance

viii) assign a zonation system, based on site specific criteria

ix) review and update the model on a regular basis.

The methodology for evaluating the slope stability hazards for coastal cliffs can be achieved in the Tonkin and Taylor Limited method by taking the following steps:

- Collect data
- Visit site
- Assess stability by
  - i) identifying physical characteristics
  - ii) identifying geological controls
  - iii) identifying slope failure mechanisms
  - iv) consider historic slope performance
  - v) assess effects of changes in slope condition
  - vi) consider how stability may change with time
  - vii) subdividing the cliff into sections of different slope characteristics, failure modes and predicted retreat rates
- Establish criteria for hazard zonation and assign hazard zonation in accordance with defined criteria.

The data required to evaluate cliff stability is very similar to that required for the evaluation of sandy beaches. The range of data sources includes:

- ♦ Aerial photographs (vertical aerial photographs are considered to be essential)
- ♦ Geological maps
- ♦ Topographical maps
- ♦ Survey Data
- ♦ Historical reports

- ♦ Hazard register information
- ♦ Anecdotal accounts
- ♦ Site-specific ground investigation data.

The object of the data collection is to provide information on a range of physical, geological, erosion, coastal and human influence factors. These are set out in more detail in the Tonkin and Taylor Limited report (Tonkin and Taylor Limited;1998, 23).

A site visit is essential as much of the data for cliffs is very site specific. The site inspection should be carried out by a suitably qualified person with relevant experience. The assessment of stability needs to recognise that different sections of a cliff will exhibit different geological characteristics and may have different failure mechanisms. Division of the cliff into subsections based on discrete areas of homogenous geology and/or failure is therefore important. The Tonkin and Taylor Limited report also stresses that several failure mechanisms may control the stability and shape of the slope at any one location on a range of scales. Each failure mode should be noted and an account of expected failure size and frequency given.

Specific knowledge of the cliff instability in an area allows for calibration of the slope failure model developed using the above process. Where reliable data exists, the average rate of cliff retreat should be determined for as long a period as possible. Principal modes of failure and any cyclical patterns should also be identified. Note should be taken of varying patterns of retreat, such as large scale long term retreat superimposed by frequent small scale rock falls. Changes should also be assessed in the context of the coastal environment of the area, and any changes in hydraulic or sedimentary sub-aqueous processes (including storm events) should be investigated if relevant.

According to Tonkin and Taylor Limited, there are several time dependent factors that are likely to change as the cliff retreats, and human development changes hydraulic and hydrological patterns in the immediate vicinity. Any cliff stability model must take these into account when determining a rate of retreat. These include:

- ◊ changes in geology as the cliff face retreats/develops
- ◊ changes in toe erosion rates due to sea level rise

- ◊ changes in toe erosion rates due to development of the shoreline
- ◊ changes to stormwater runoff patterns above the cliff line
- ◊ changes to land use (above and below the cliff line)
- ◊ any stabilisation work undertaken to improve cliff stability

Determination of a Hazard Zone

The Tonkin and Taylor Limited reports notes that the criteria for establishing the zonation boundaries may vary from site to site and it is important that these criteria are clearly specified. In the majority of cases, cliff line retreat is the criteria for zonation. Tonkin and Taylor Limited recommend that zonation for cliffs should include as few a number of zones as possible. A categorisation into “High”, “Medium” and “Low” risk areas is considered acceptable by the report. Any further detail is not considered warranted due to the complexity of cliff retreat processes, and the geological variation within even small sections of cliff. As with sandy coasts, each zone width should be rounded to the nearest whole number to avoid false precision.

The Tonkin and Taylor Limited report emphasises that the exact methodology for each site will vary depending on site conditions and the requirements of the assessment. They also refer to new data processing technology for aerial photography to capture a record of over 50 years of erosion. This involves digital imaging from the aerial photographs, fixed in x-y space using historically fixed features, to determine the top and bottom of the cliff lines.

The report considers it important to distinguish between cliffs that have active erosion at the toe and those which have their toe stabilised by engineering works (such as Tamaki Drive). Due to these structures, cliff failure represents a finite adjustment process which will occur for a finite period of time.

APPENDIX 3

Relevant Statutory Provisions

<u>Resource Management Act</u>

The purpose of the Act is set out in Section 5 of the Act, which states:

"(1) The purpose of this Act is to promote the sustainable management of natural and physical resources.
(2) In this Act, "sustainable management" means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while-

> (a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and
> (b)Safeguarding the life-supporting capacity of air, water, soil, and ecosystem; and
> (c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Section 6 of the Act sets out the Matters of National Importance, which include:

(a) The preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins,, and the protection of them from inappropriate subdivision, use and development:
(b) The protection of outstanding natural features and landscapes from inappropriate subdivision, use and development:
(c) The protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna:
(d) The maintenance and enhancement of public access to and along the coastal marine area, lakes, and rivers:

Section 7 of the Act sets out other matters, which include:

(b) The efficient use and development of natural and physical resources:
(c) The maintenance and enhancement of amenity values:
(d) Intrinsic values of ecosystems:
(f) Maintenance and enhancement of the quality of the environment:
(g) Any finite characteristics of natural and physical resources:

Section 30 of the Act sets out the functions of regional councils[6], and includes:

(c) The control of the use of land for the purpose of-

(iv) the avoidance or mitigation of natural hazards

Section 31 of the Act sets our the functions of territorial authorities under the Act, and includes:

(b) The control of any actual or potential effects of the use, development, or protection of land, including for the purpose of the avoidance or mitigation of natural hazards and the prevention or mitigation of any adverse effects of the storage, use, disposal, or transportation of hazardous substances.

The New Zealand Coastal Policy Statement

Principles of the NZCPS

1. Some uses and developments which depend upon the use of natural and physical resources in the coastal environment are important to 'the social, economic and cultural wellbeing' of 'people and communities'. Functionally, certain activities can only be located on the coast or in the coastal marine area.

2. The protection of the values of the coastal environment need not preclude appropriate use and development in appropriate places.

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[6] For a full discussion of the relevant roles of Regional Councils and Territorial Local Authorities in relation to coastal hazards, refer to (at least) the following cases:

i) Application for a Declaration by the North Shore City Council, Waitekere City Council, The Papakura District Council and the Rodney District Council A 87/94;

ii) Application for a Declaration by the Canterbury Regional Council A 89/94

7. The coastal environment is particularly susceptible to the effects of natural hazards.

12. The ability to manage activities in the coastal environment sustainably is hindered by the lack of understanding about coastal processes and the effects of activities. Therefore, an approach which is precautionary but responsive to increased knowledge is required for coastal management.

13. A function of sustainable management of the coastal environment is to identify the parameters within which persons and communities are free to exercise choices.

The policies of the NZCPS include:

3.2.1 Policy Statements and plans should define what form of subdivision, use and development would be appropriate in the coastal environment, and where it would be appropriate.

3.2.2 Adverse effects of subdivision, use or development in the coastal environment should as far as practicable be avoided. Where complete avoidance is not practicable, the adverse effects should be mitigated and provision made for remedying those effects, to the extent practicable.

3.3.1 Because there is a lack of understanding about coastal processes and the effects of activities on coastal processes, a precautionary approach should be adopted towards proposed activities, particularly those whose effects are as yet unknown or little understood. The provisions of the Act which authorise the classification of activities into those which are permitted, controlled, discretionary, non-complying or prohibited allow for that approach.

3.3.2 Local authorities shall share information and knowledge gained by them about the coastal environment, particularly where it relates to coastal processes and/or activities with previously unknown or little known effects.

3.4.1 Local authority policy statements and plans should identify areas in the coastal environment where natural hazards exist.

3.4.2 Policy statements and plans should recognise the possibility of a rise in sea level, and should identify areas which would, as a consequence be subject to erosion or inundation. Natural systems which are a natural defence to erosion and/or inundation should be identified and their integrity protected.

3.4.3 The ability of natural features such as beaches, sand dunes, mangroves, wetlands and barrier islands, to protect subdivision, use, or development should be recognised and maintained, and where appropriate, steps should be required to enhance that ability.

3.4.4 In relation to future subdivision, use and development, policy statements and plans should recognise that some natural features may migrate inland as a result of dynamic coastal processes (including sea level rise).

3.4.5 New subdivision, use and development should be so located and designed that the need for hazard protection works is avoided.

3.4.6 Where existing subdivision, use or development is threatened by a coastal hazard, coastal protection works should be permitted only where they are the best practicable option for the future. The abandonment or relocation of existing structures should be considered among the options. Where coastal protection works are the best Practicable option, they should be located and designed so as to avoid adverse environmental effects to the extent practicable.

Under the Act, the primary responsibility for the control of the use of land for the avoidance or mitigation of natural hazards lies with regional councils and territorial authorities. However, the exact role of each of these agencies is not specifically in the Act. Rather, Section 62(1) of the Act requires each RPS to specify the relevant responsibilities of each regional and territorial authority in relation to the control of the use of land for the avoidance or mitigation of natural hazards.

Chapter 11 of the proposed ARPS addresses natural hazards. Methods 11.4.2 state that:

"10 The ARC will implement objectives, policies and rules with respect to coastal hazards in the coastal environment, through the provisions in the Regional Plan- Coastal, which will encourage subdivision, use and development in the coastal environment to locate in appropriate areas.

11 In consultation with the TA's, the ARC will develop and maintain a regional coastal hazards database, and provide information on appropriate methods of avoiding, remedying, or mitigating the adverse effects of coastal hazards, including sea level rise.

12 *TA's will implement objectives, policies and rules with respect to coastal hazards through provisions in district plans, including the use of esplanade reserves and strips."*

The proposed Regional Plan: Coastal contains detailed provisions relating to coastal hazards in Chapter 20. The issues, objectives and policies of that chapter are set out below.

"20.2 ISSUES

20.2.1 Physical processes in the coastal environment, such as erosion, inundation, land instability, rising mean sea level, and tsunami, may act to adversely affect human life, property, or other aspects of the environment, causing coastal hazards. There is often a need to avoid, remedy, or mitigate the adverse effects of these hazards.

20.2.2 Inappropriate subdivision, use, and development may cause or exacerbate natural coastal hazards, create new risk, or unnecessarily place human life and property under threat from these hazards.

20.3 OBJECTIVE

20.3.1 To control the use of land in the coastal environment to ensure the adverse effects of natural coastal hazards area avoided or mitigated.

20.4 POLICIES

20.4.1 New subdivision should be located and designed to avoid interference with natural coastal processes, including those of natural coastal features, that have a tendency to change or migrate inland as a result of climate and sea-level changes, so that the need for coastal protection measures is avoided.

20.4.2 Where existing subdivision, use, and development in the coastal environment is adversely affected by coastal hazards, including mean sea level rise, further subdivision, use, and development that exacerbates the coastal hazard, or creates a new coastal hazard, should be avoided.

20.4.3 Natural features such as beaches (including sand dunes and longshore bars), mangroves, and wetlands, which may buffer subdivision, use, and development from coastal hazards, shall be protected.

20.4.4 Coastal protection measures should generally use non structural methods, *including planting and beach nourishment, rather than structural methods, such as seawalls, which artificially stabilise the coastline, unless it can be demonstrated that a structural solution is the best practicable method for remedying or mitigating the hazard.*

20.4.5 Coastal protection measures in Coastal Protection Areas 1, Tangata Whenua Management Areas, or any place or area scheduled for preservation in Cultural Heritage Schedule 1, shall be avoided where their effects would result in more than minor modification or damage to, or the destruction of, the values contained in these places or areas.

20.4.6 The relevant provisions of the Values Chapters (3 to 9) shall be considered in the assessment of any coastal protection measures.

20.4.7 Structural coastal protection measures will be assessed in accordance with all relevant policies of Chapter 11, Structures.

20.4.8 In assessing the effect that a rise in mean sea level may have on subdivision, use, development and protection of the coastal environment, the best available estimate of mean sea level rise for the locality in question shall be used.
NB: Refer to Other Method 20.6.6 regarding the best available estimate.

20.5 RULES

This section contains no rules. However, rules pertaining to coastal protection structures, beach nourishment, and planting may be found in Chapters 11: Structures, 16: Deposition, and 17: Planting and Introduction of Plants, respectively.

20.6 OTHER METHODS

20.6.1 The ARC will, in consultation with TLAs:

- *a develop a regional methodology for the identification of natural coastal hazards, including areas which could be subject to erosion or inundation as a result of mean sea level rise;*
- *b maintain a database of identified natural coastal hazard areas;*
- *c undertake research on the risks and impacts of natural coastal hazards, particularly those that are regionally significant; and*
- *d undertake research on methods to avoid, remedy, or mitigate natural coastal hazards.*

The ARC will make this information available to TLAs and the general public.

20.6.2 The ARC, in consultation with relevant parties, will establish monitoring programmes for natural coastal hazards of regional significance, and make this information available to TLAs and the general public.

20.6.3 The ARC will develop and carry out educational strategies aimed at providing the general public with a greater understanding of risks associated with natural coastal hazards, and how these risks are being addressed throughout the Region.

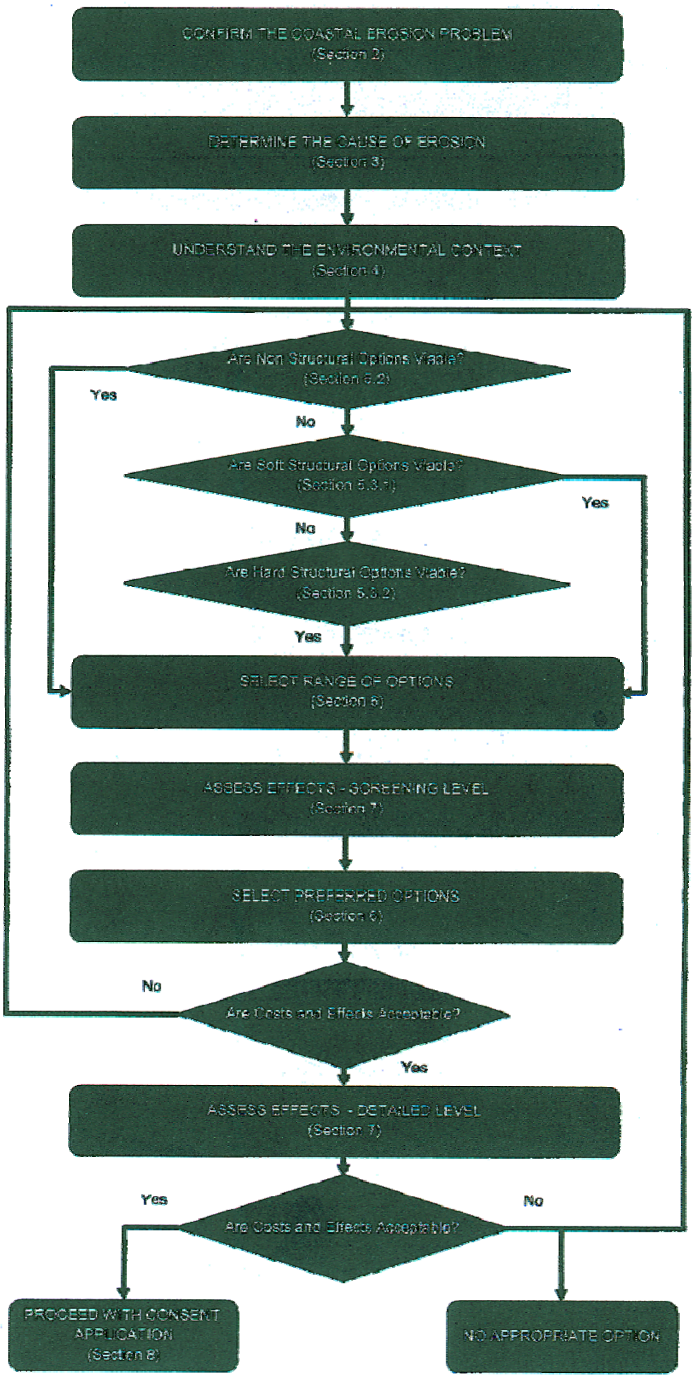
20.6.4 The ARC will encourage the active involvement of local communities in developing and implementing coastal hazards management programmes.

20.6.5 The ARC will support the development of Comprehensive Coastal Management Plans which take an integrated approach to managing hazards which occur within the coastal environment.

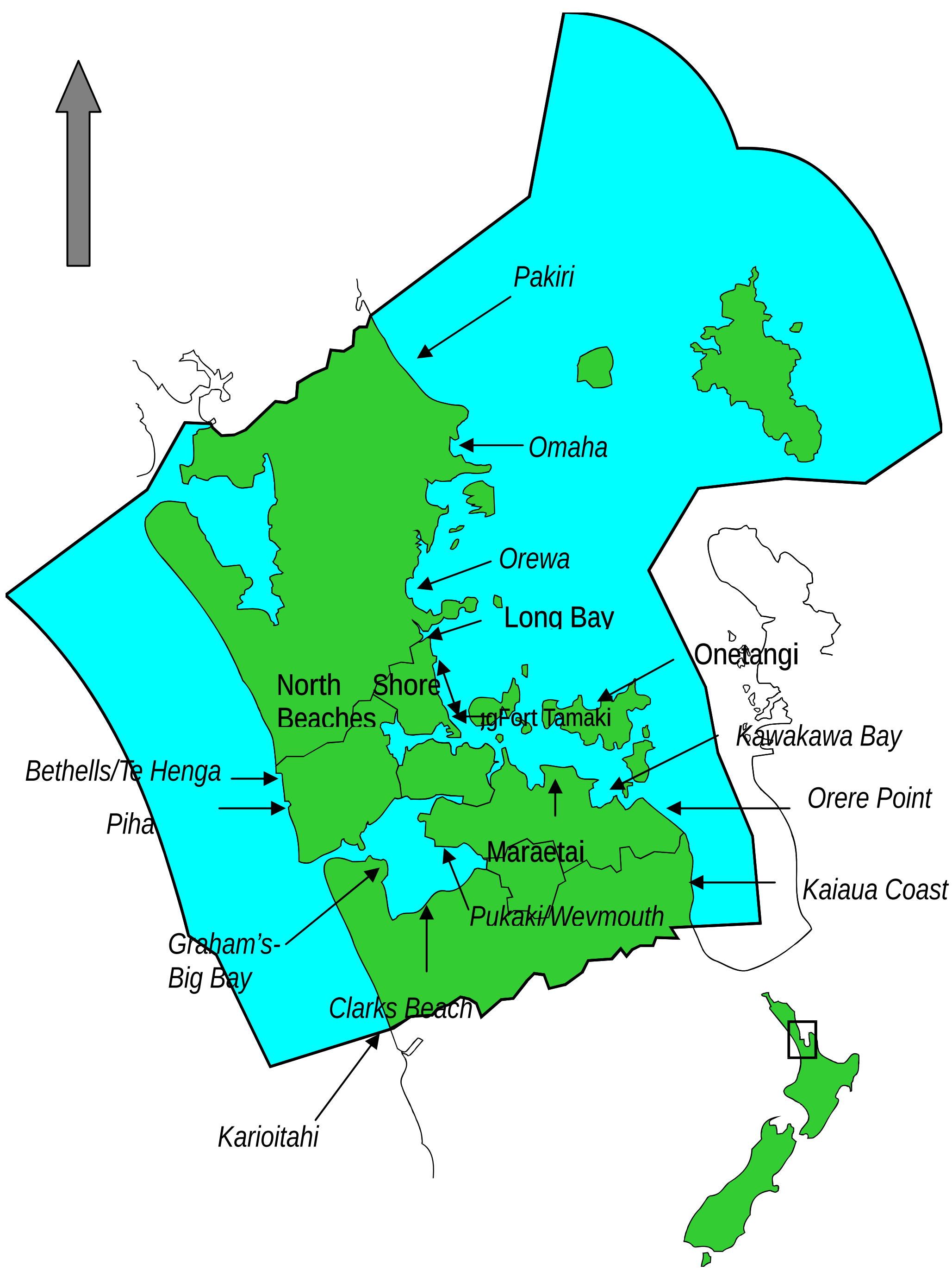
20.6.6 The ARC will maintain information on the best available estimate for mean sea level rise, and make this information available to TLAs and the general public.

20.6.7 District plans should contain appropriate provisions to implement the policies in this chapter.

APPENDIX 4 CONTENT OF THE COASTAL EROSION MANAGEMENT MANUAL (CEMM)



APPENDIX 5 LOCATION MAP OF PROPOSED COASTAL HAZARD EVALUATION SITES



Note.
Priority sites (refer Table 2) are shown in **Bold**.
Other sites listed in Table 2 are in *Italics*

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